A MULTI-OBJECTIVE LINEAR PROGRAM MODEL TO TEST

HUB-AND-SPOKE NETWORKS AS A POTENTIAL

AIR FORCE DEPLOYMENT ALTERNATIVE

THESIS

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Abstract

The purpose of this research is to develop a multiple-objective mixed-integer linear programming model that determines the feasibility of a new deployment paradigm, which offers greater flexibility to home station and deployed location civil engineers (CE) by applying hub-and-spoke networking. The research covers the histories of CE and Air and Space Expeditionary Force (AEF), current CE deployment needs, multiple-objective decision analysis, hub-and-spoke networking, and organizational behavior benefits of the new paradigm. The methodology section provides details on each objective, explains the model, defines weights, and explains the objective function's calculation. Next, an analysis of the model's resulting scenarios helps determine the appropriate parameters. Research conclusions and recommendations for potential future study are provided. Some of the new paradigm's benefits include the consolidation of coordination, training, equipment, travel, and other mobility related activities. The paradigm provides home station and deployed CE leaders with greater control over the mobilization of their resources. This control should help to reduce fluctuations in home station manpower levels, and deployment to the same location should make the process easier for everyone involved. A final added benefit to regional clustering is that it opens the door to improved networking between active duty and guard/reserve components.

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Andrew J. Cullen

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1. INTRODUCTION

1.1 Chapter Overview

This chapter summarizes the background and motivation for this research and provides the research objectives. Additionally, it defines the methodology employed in the research as well as known assumptions and limitations. Chapter 1 concludes with an overview of the remaining four chapters of the thesis.

1.2 Background and Motivation

In 2000, the Air Force introduced a new deployment-scheduling paradigm, called Air and Space Expeditionary Force (AEF), with the intent of making deployments more predictable, and assignments more fairly distributed. Based on the preexisting paradigm used by the US Marines, AEF divides bases approximately equally into a set number of manpower pools, known as buckets. The current construct uses ten of these buckets to capture the Air Forces' entire mobility manpower pool. One deployment cycle consists of five equally spaced periods, each supported by a pair of buckets. The current standard tour length is set at four-months, such that all AEF bucket pairs, when placed end to end, cover a total of 20-months, or one cycle.

Since its inception, AEF has gone through a number of policy changes. Included in these are a reduction in the total number of buckets, an extension of standard tour lengths, the adjustment of base bucket assignments, and other specialized policies created to address issues unique to career fields, such as aircraft rotation, and use of low-density,

high-demand personnel such as Security Forces and Explosive Ordinance Disposal (EOD) experts.

The Civil Engineer (CE) career field currently falls under the generalized rules of AEF policy. A typical unit divides its deployable personnel into two, non-back-to-back, buckets, such that a squadron can expect to have up to 40% of its manpower gone for four to six months, twice every cycle. Before, during, and briefly after every tasked bucket, stress levels within the unit are often high, as nearly half of the unit is preoccupied with the effects of deployments. During these periods of low-manpower, high-stress, and undeterred ongoing operations, CE commanders, or Base Civil Engineers (BCE), walk a fine line of balancing mission requirements, unit moral, programs, special projects, limited manpower capabilities, and over hire budgets which, if funds are available, may help to relieve some of the added stresses. Multiplying this effect by two, to account for both assigned buckets, the average unit faces this situation, often referred to as a 'break the base' scenario, on average between 11 to 15 months, during every 20-month AEF cycle. Chapter 2 provides more details on this topic.

Complicating the process further, there are often times when a tasked base cannot meet a particular, or collection of, deployment assignments. This is what the Air Force calls a shortfall, and may result in the deployment of personnel outside of the scheduled buckets. During the Air Forces' previous AEF cycle, a culmination of shortfalls led to a snowball-effect that drove the need to extend tours and create special buckets to allow the process to get back on-track for the next cycle, thus negating the predictability element.

The current system also presents a dichotomous problem. On one hand, deployment managers demand a quick response to addressing requirement changes; however, the network of change approval personnel is so broad that it results in slow responses to requirement changes. The process begins with the BCE at the deployed location, who identifies the change in requirements to Central Command Air Force (CENTAF) deployment managers, who then notify the AEF cell functional manager, followed by the Major Command (MAJCOM) deployment manager, the home-station Unit Deployment Manager (UDM), the BCE, and finally the individual needed. If the unit is unable to fill the tasking, formal approval of the shortfall by the two levels of management over the BCE is required before notifying the MAJCOM deployment manager, who may then have to forward the shortfall back to the AEF center. Throughout this entire process, the BCEs at both the deployed location and home-station have little say or control over the outcome.

Some final issues that result from current AEF policies and deployment management are the lack in continuity and diminished long-term effectiveness of the civil engineer mission at deployed locations. As stated earlier, the standard tour length is currently set at four-months. However, in some cases, the extension of tour lengths to between six-months and one-year helps to minimize the effect of turnover and accommodates some manpower constraints. This results in competing objectives between increasing effectiveness of deployed engineers and minimizing the length of tours for the benefit of the military member and their families.

1.3 Research Objectives

The current practice of deployment management is status quo; continuing to work under the restrictions of AEF policy. This research's purpose is to develop an alternative deployment paradigm that offers greater flexibility to home station and deployed location BCEs using hub-and-spoke networks. The model developed by this research groups CE squadrons together, such that, as a whole, each cluster possess the necessary work force to operate one deployed location for one full cycle. This paradigm employs a hub-and-spoke model, which assigns one base as the focal point for consolidated coordination, training, equipment, travel, and other mobility related issues. The paradigm uses a fixed shared command, which allows BCEs to adjust tour lengths to meet individual needs; for example, some members of a given team may wish to spend more than just four-months in theater, thus negating or reducing the requirement in the next bucket.

Flexibility also allows for the violation of another AEF policy under this alternative, by not forcing units to place its entire manpower pool into only two buckets. Instead, units can spread deployment requirements across all buckets, resulting in fewer manpower level fluctuations, potentially never dropping below 80% throughout the cycle. Since every deployment would go to the same location, under the same field conditions, and under a prearranged manpower plan, the process of getting individuals from home-station to the forward operating base (FOB) should become easier for UDMs.

A hub-and-spoke network can also serve as a means to develop regions, allowing for a potentially simpler means of incorporating local guard and reserve forces into the mobility equation. From a non-mobility perspective, this model builds networks between

regional active duty, guard, and reserve units, which may prove useful in forming mutual aid agreements to help respond to events such as natural disaster recovery or terrorism.

In a non-military application, this research is a valuable study into how regional teaming is useful for increasing efficiency in large corporations who have many satellite offices, such as chain retailers or restaurants. The determination of the best hub-and-spoke clusters involves the application of a multiple objective linear programming model; therefore, this research also adds to the growing academic pool on this subject.

1.4 Methodology

Determining the best hub-and-spoke solution is a model that uses mixed-integer decision variables within Microsoft Excel and Frontline's premium solver package. The model includes multiple objectives, dependent upon input from the decision maker, that include; minimize total mileage between spoke and hubs, maximize airlift capability, maximize number of cold weather bases supporting a cold weather FOB, maximize number of missions matched between clusters and FOBs, and maximize manpower.

1.5 Scope, Assumptions, and Limitations

According to the October 2006 CE manpower assessment, known as the Blue Suit Review, the career field includes over 36,000 military positions. This research focuses in on the majority of that manpower pool; the *traditional engineer* job specialties, which include officers, electricians, power production, utilities, structures, heating-ventilation and air-conditioning (HVAC), heavy equipment operations, controllers, engineer assistants, and liquid fuels. Not included in the research are EOD technicians and fire fighters, which both already have their own specialized AEF deployment methods. The

model also excludes CE Readiness, which accounts for such a small number of mission driven deployments that it does not make logical sense to include it in this research. Chapter 2 discusses in detail further necessary scoping such as the model being limited to only continental United States (CONUS) Air Force bases with 50-plus traditional engineers. A final limitation comes from the data, which was current at the beginning of the research, and reflects total force numbers, not actual deployable force numbers.

1.6 Preview of Thesis

The literature review section, found in Chapter 2, provides a brief history on the AEF deployment concept, specifically with respect to its impact on the CE community. It continues by defining CE's current deployment needs and common limiting factors facing today's leaders. Chapter 2 concludes by detailing the research done in determining the best methodology to apply to this study, specifically on multiple objective decision analysis, hub-and-spoke network problems, and the software used in this research. Chapter 3 continues the discussion of methodology, by providing details on defining the objective function, building the model, and defining the weights for each objective. Next, an iterative process of testing and analyzing the models parameters produces test scenarios, each of which represents a potential hub-spoke network solution that meets the model's defined parameters. Chapter 4 then examines these scenarios, provides multiple levels of analysis for each, and identifies which of them is the best choice for implementation. Finally, Chapter 5 lists any research conclusions, makes recommendations for potential future study, and recommends actions to Air Force CE leadership based on research findings.

2. LITERATURE REVIEW

2.1 Chapter Overview

Before discussing details of methodology and results, it is essential to review any key elements that provide a foundation for this research. Chapter 2 begins with a brief history of the Air Force's AEF deployment system along with some details on the past and present challenges faced by the Civil Engineer community during deployments. The chapter next examines network flow problems, specifically hub-and-spoke networks, and investigates how they are applicable to this research. Following this is a detailed analysis on advantages and disadvantages of a hub-and-spoke paradigm. The chapter concludes by looking at the decision analysis process for multiple objective problems and presents a brief explanation of the software used.

2.2 Brief History of CE and AEF

Air Force Civil Engineers can trace their heritage back to pre World War I, when the U.S. Army Signal Corps created a small unit of engineers to specialize in construction of support facilities for signal balloons. During World War II, Aviation Engineers fulfilled a much larger role, employing more than 100,000 personnel with the critical responsibility of constructing or reconditioning nearly 250 airfields in the European theater, and 1,435 airfields in 67 countries to support Allied forces throughout the war. In 1947, the Air Force became a separate branch of service, and in the 1950s, with the introduction of Inter-Continental Ballistic Missiles, the Department of Defense (DoD) recognized the need for an Air Force Civil Engineer function, independent of the Army Corp of Engineers, and established the Air Force Director of Civil Engineering office in

1959. CE continued to play a major support role to the Air Force during the Korean War and Vietnam conflict, making progressive improvements on camouflage, hardening, airfield repair, after attack recovery, and tent-city construction. In 1964, CE revolutionized the way it trained and deployed by developing specialized teams, composed of a mixture of engineering skills and expertise, known as Prime BEEF (Base Engineer Emergency Force) teams. Today's Prime BEEF teams are composed of personal specializing in interior and exterior electric, power production, plumbing (utilities), HVAC, structural (vertical) construction, heavy equipment and pavement (horizontal) construction, production control, engineering assistance, pest management, liquid fuels, and CE leadership including officers and senior enlisted managers. The 70s and 80s brought further improvements to CE contingency materials and equipment, which proved successful during the Gulf War, when more than 3,000 engineers bedded down 55,000 people at nearly 30 sites. (AFPAM 10-219 Vol 1, 1995)

The Gulf War was also the last time the Air Force employed the PALACE TENURE deployment management program. PALACE TENURE was a product of the cold war, and operated by filling positions on an individual level. In its place, the Air Force implemented the AEF concept, which boasted greater stability, predictability, and use of teaming. As part of the AEF, CE falls into the Expeditionary Combat Support (ECS) function, most of which follows a very generic deployment cycle. (Stewart, 2006)

Since its inception, the AEF process has evolved and matured to meet the dynamic needs of the Air Force. In October 1999, when AEF first began, each cycle consisted of five AEF pairs, which were deployed for 90-days each, for a total cycle

duration of 15-months. This continued for the first three cycles with only minor changes. However, the September 11, 2001 attacks, Operation Enduring Freedom, and Operation Iraqi Freedom, triggered an increase in deployments, and necessitated a policy change to a minimum of 120-day deployments; and thus a 20-month cycle. (Snyder et al, 2006) Figure 2.1 below provides a graphical depiction of the AEF Cycle 6. (Briefing AEF 101, 2006:slide 11)

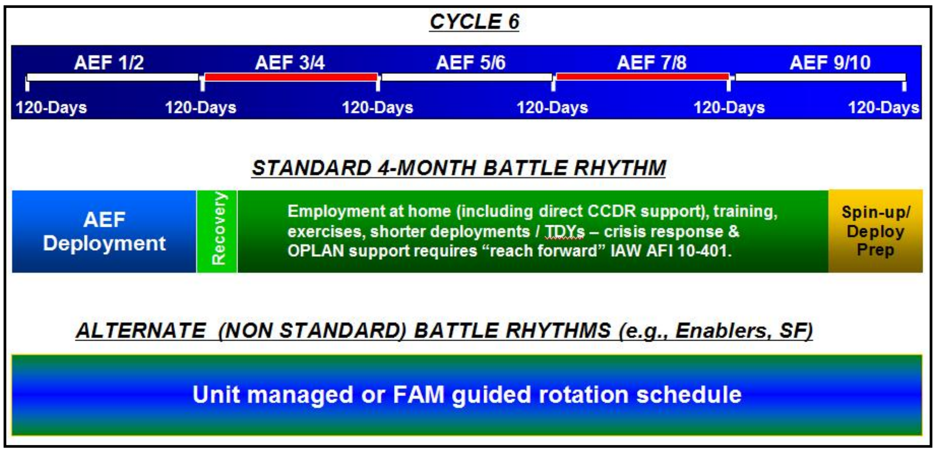


Figure 2.1 - A Graphical Depiction of AEF Cycle 6

One guiding principal to AEF that has not changed for the standard cycle is the *2-hit policy*. According to Air Force Instruction (AFI) 10-400, section 7.12.4.1.1 (2005), "Bases providing ECS UTCs (Unit Type Codes, or simply teams) will only be hit twice per AEF cycle; i.e., forces from a particular base will be aligned to only two on-call periods during the AEF cycle. Furthermore, these two on-call periods will not be back-to-back." The initial purpose behind this policy was to allow for the matching of ECS personnel with aircrew and maintainers from the same location, thus improving overall team cohesion at the deployed location. However, this is not always possible since there

is often no synchronization between resources and tour lengths. (Stewart, 2006:p7) Of course the more obvious perceived benefit for the 2-hit policy is that units have to worry about deployments only twice during a cycle, and theoretically could operate fully manned during the remaining 60% of the time. This, however, is not always the case given the current state of deployments.

2.3 Current CE Deployment Requirements

A recent CE briefing at Air Force Headquarters identified the following current issues: operations tempo is greater than ever before, AEF is not working for the “long war”, and 60% of CEs deploy for 6 months or longer, breaking UTC capabilities and team integrity. (Briefing, Civil Engineer Traditional Ops UTC Transformation, 2006:slide 30)

Further complicating the issue is a recent initiative, titled Presidential Budgeting Directive (PBD) 720, that seeks to trim down Air Force manpower authorizations across nearly every career field. In 2006, facing a work force already stretched thin due to current operations, CE leadership launched a Blue Suit Review, with the purpose of determining the minimum number of CE personnel needed to meet the requirements of the 2006 Quadrennial Defense Review (QDR). The QDR outlines the strategy of the Department of Defense, and in turn the Air Force, for steady state and surge operations. In 2001, the wartime construct was 1-4-2-1, meaning protect “1” homeland, operate in “4” regions (Europe, the Middle East, the Asian Littoral, and Northeast Asia), wage “2” nearly simultaneous campaigns, and in “1” of those campaigns manage a regime change. However, in 2006, this strategy was updated to 1-N-2-1, using "N" to represent the need

to be able to respond to global conflicts. (QDR Report, 2006:pp36-39) The findings from the Blue Suit Review were that of the current 36,080 military members, CE needs a minimum of 33,056 to meet on-going mission requirements, meaning CE could sustain an approximately 5.1% cut in its work force. Table 2.1 and Figure 2.2 provide a summary and map of home-station Prime BEEF manpower levels. (Briefing, Air Force Civil Engineers for the 21st Century, 2006:slide 30 and supplemental data)

Table 2.1 - Home-Station Prime BEEF Manpower Authorizations

8* CONUS with 200+ Prime BEEF Personnel (*includes two base pairings)					
Holloman	344	Travis	222	Shaw	213
Nellis	237	Langley	219	Ellsworth	204
Minot	227	*Hurlburt Fld / Tyndall*	*215*		
9 CONUS with 150-199 Prime BEEF Personnel					
Andrews	199	Davis-Monthan	170	Whiteman	166
Vandenberg	188	Beale	169	Seymour Johnson	159
Peterson/Schriever/Buckley	184	Malmstrom	166	McGuire	150
16 CONUS with 100-149 Prime BEEF Personnel					
Dyess	144	FE Warren	126	Little Rock	112
Grand Forks	144	Fairchild	125	Luke	112
Scott	140	Mountain Home	125	Patrick	110
Dover	139	Charleston	116	McConnell	106
Barksdale	130	McChord	114		
Cannon	130	Moody	113		
5 CONUS with 50-99 Prime BEEF Personnel					
Altus	93	Lackland	74	Tinker	67
Sheppard	89	Robins	72		
15 OCONUS with 50+ Prime BEEF Personnel					
Ramstein	438	Eielson	223	Yokota	152
Kadena	323	Anderson	189	Lakenheath	126
Spangdahlem	323	Hickam	188	Kunsan	123
Elmendorf	294	Misawa	185	Lajes	84
Osan	261	Aviano	162	Mildenhall	73
Not Listed					
10 Bases with 20-49 Prime BEEF Personnel and 89 Bases with 1-19 Personnel					

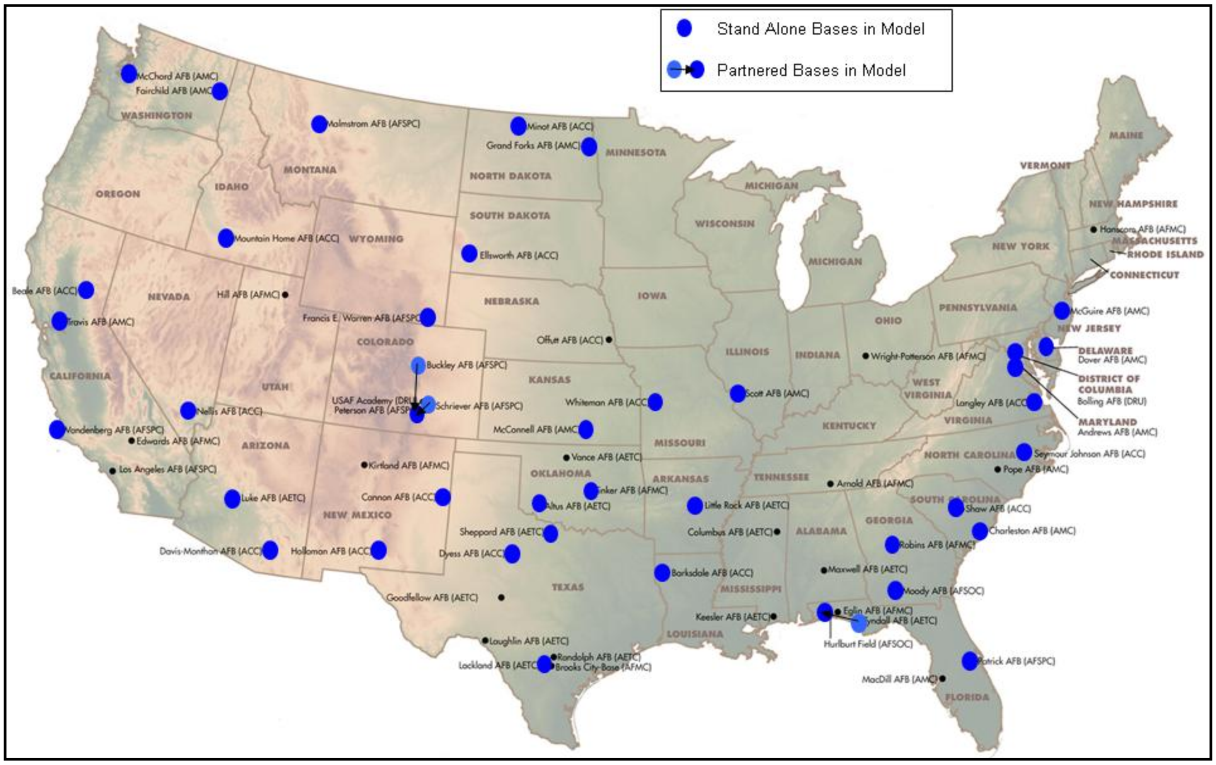


Figure 2.2 - Map of CONUS Bases with 50+ Prime BEEF Personnel

To support this likely reduction in force, CE leadership collected data on current deployment requirements at all major Forward Operating Bases (FOB) to enable the investigation of other alternatives. Table 2.2 below shows a summary of this data. (Briefing, Civil Engineer Traditional Ops UTC Transformation, 2006:supplemental data) Reducing the scope of FOB requirements allows for further simplification of the problem, by eliminating Eskan Village from the model due to its low demand, and by merging Bagram and Kandahar due to their low demands and proximity with-in the region. Section 3.2.3 addresses these results.

Table 2.2 - CE Deployment Requirements as of Oct 2006

FOB	Officers	Chief	Superintendent	First Sergeant	Supply	Electrical	Power Pro	HVAC/R	Pavements	Structural	Utilities	Liquid Fuels	Pest Mgt	Engineering	Operations Mgt	TOTAL
Al Udeid	10	1	4	1	6	32	10	36	32	29	34	0	2	14	6	217
Al Dhafra	3	1	3	1	2	10	7	9	8	7	8	2	2	3	2	68
Ali Al Salem	7	2	4	1	2	8	16	12	8	8	10	2	2	8	3	93
Balad	6	1	5	1	4	15	22	15	16	12	18	2	2	5	4	128
Eskan Village	1	0	0	0	0	0	2	0	0	0	0	0	1	1	1	6
Ali Base	4	1	5	1	2	8	16	9	12	7	9	0	2	3	2	81
Kirkuk	6	1	4	1	2	8	4	9	8	8	13	0	2	5	3	74
Bagram	1	0	0	0	2	3	6	0	12	3	0	0	0	3	0	30
Manas	5	1	4	1	2	7	2	9	8	10	8	0	2	3	2	64
BIAP	4	1	3	1	2	7	12	9	8	7	8	2	2	3	2	71
Kandahar	1	0	0	0	0	2	0	0	8	2	0	0	0	1	0	14
Total	48	9	32	8	24	100	97	108	120	93	108	8	17	49	25	846

With this data at hand, CE leadership has been looking at alternatives to the current AEF construct to include new rotational alignments, the number of AEF pairings (i.e. "buckets") per cycle, the number of requirements at the FOBs, and restructuring CE team compositions. One idea is to adopt a deployment schedule similar to that of CE EOD experts, placing all CE Prime BEEF personnel into one of three buckets and deploying each bucket for six months. This alternative generates an 18-month cycle, with each bucket receiving a 12-month recovery and training period. Another alternative being considered is breaking apart the large 55-person and 40-person Prime BEEF teams into 26-person teams; providing the advantage of greater flexibility in deployment assignments while maintaining team integrity. (Briefing, Civil Engineer Traditional Ops UTC Transformation, 2006:slides 5 and 35). A new technique that will soon be tested with the CE fire community is one that ignores the 2-hit policy by dividing unit mobility

members into four or five of the buckets, thus minimizing the drop in home-station manpower during deployments. (Interview with AF/A7CXX on 2 May 2007)

2.4 Network Flow Problems and Hub-and-Spoke Networks

This research explores a combination of the above ideas in addition to a fourth element which utilizes inter-base teaming via hub-and-spoke networks. Hub-and-spoke networks are a special case of network flow problems, which all have a common characteristic that "they can be described or displayed in a graphical form known as a network." Common examples of network flow problems include: transshipment problems, where resources must be moved through a network at the least cost; shortest path problems, where one unit of a resource must be moved from point A to point B with the least cost or distance; and transportation or assignment problems, where supply and demand principals must be met while minimizing cost. (Ragsdale, 2007:pp177-193)

Hub-and-spoke network problems are a specific category under generalized network flow problems. Some common examples of where the industry uses hub-and-spoke networks include airlines, postal and delivery services, and computer networks. In each case, hubs serve as a focal point to gather in resources from many locations, and redistribute them from the hub to get the resource to its end destination. (Thore and Fedele, 2005:p2) However, another characteristic that all the above networks share is the interconnectivity of all nodes; therefore, a more accurate model for these real-world examples might be a minimum spanning tree. (Ragsdale, 2007:p208)

The three major components of a hub-and spoke network are supply nodes, transshipment nodes, and demand nodes. According to rules of *balance-of-flow*, various

constraints apply at each of these nodes. Considering that for this problem the total supply of personnel must be greater than or equal to the total demand, the following applies at each node in the network:

$$\boxed{\text{Inflow} - \text{Outflow} \geq \text{Supply or Demand}}$$

What this essentially means is that at supply nodes, the outflow must be less than or equal to what is available. At transshipment nodes, the inflow will equal the outflow, and at demand nodes, the inflow must be greater than or equal to the demand. (Ragsdale, 2007:p180) Section 3.2 discusses in detail the application of hub-and-spoke networking to this problem.

2.5 Alternative Advantages and Disadvantages

When considering any alternative as a potential solution to a problem, it is important to investigate the advantages and disadvantages it presents. This section investigates pros and cons to the alternative by looking at past research and explaining any intuitive deduction.

2.5.1 Advantages

The utilization of the hub-and-spoke network alternative provides for three major potential benefits when compared to the current AEF policy: 1) reemphasis on teaming, 2) mission ownership, and 3) minimized loss of manpower.

Reemphasis on Teaming

The first, and one of the most important advantages to the hub-and-spoke alternative, is a reemphasis on teaming. Organizational behavior research defines work teams as "a group whose individual efforts result in a performance that is greater than the sum of the individual inputs". The use of teaming, versus random grouping, provides for a potential increase in work output with no change in resources. (Robins and Judge, 2007:pp339-340) "Research on the effectiveness of organizational teams has suggested that use of teams has led to greater productivity, more effective use of resources, better decisions and problem solving, better-quality products and services, and greater innovation and creativity." (Northouse, 2007:p208) These key team-driven characteristics are likely factors in CE's decision to apply teaming principals in 1964 with the creation of Prime BEEF, and in the Air Force's decision to focus on teaming with the implementation of AEF.

However, as hinted at earlier, simply grouping people together at random does not create teams. For example, though AEF was created with the intention of training and deploying personnel as teams, the ever increasing demand of high operations tempo has forced this idea aside, as teams are constantly broken up to meet mission needs or individuals are simply deployed as a 'one-man team'. This produces CE squadrons at the FOBs comprised of personnel who have likely never even met, let alone worked together. So the question is what is the best way to form teams?

Recent group behavioral research studies categorized key characteristics that support the creation and development of effective teams. Figure 2.3 provides a model that summarizes these findings. (Robins and Judge, 2007:p344)

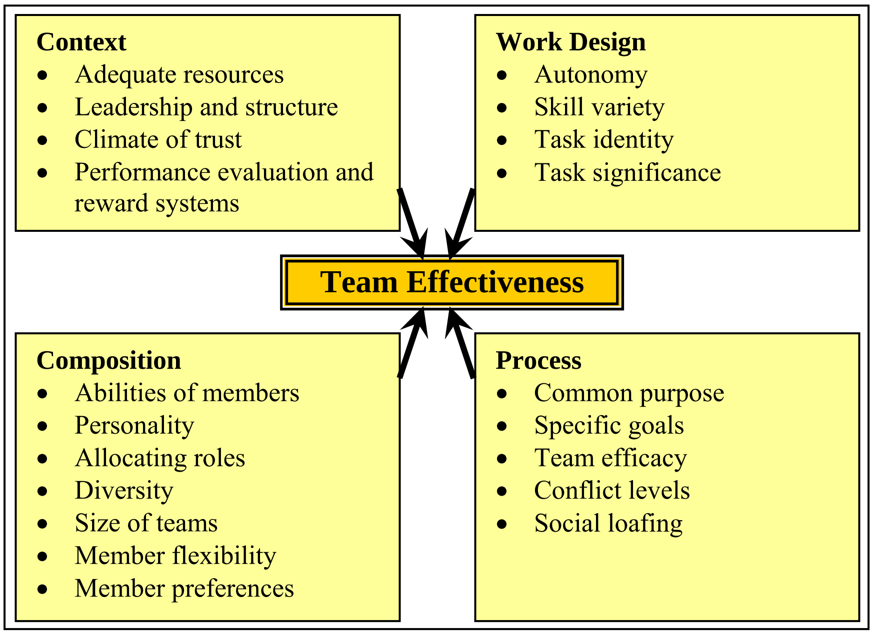


Figure 2.3 - Team Effectiveness Model

The idea of *context* relates to the situational and environmental characteristics surrounding a team such as adequate resources, leadership and structure, climate of trust, and performance evaluation and rewards systems. Based on personal experience with the current process, the deployment mission, time available until departure, and unit funds available are factors in how well individuals are equipped. This results in members from various bases arriving at an FOB with a significant difference in quantity and quality of equipment. The hub-and-spoke paradigm, however, enables teamed units to equip more evenly due to improved pre-deployment coordination. Another contextual advantage

involves the potential to consolidate the many squadron equipment pallets into fewer shared team pallets, which could be centrally stored and managed at the hub. To improve further upon the contextual elements, the new paradigm provides hub leadership with enhanced coordination of schedules, assignments, goals, environmental conditions, and recognition through awards and decorations. (Robins and Judge, 2007:pp345-346)

The *composition* element relates to how the make-up of a team can determine its overall effectiveness. Certain characteristics such as personality, diversity, and team size are under limited control, as there is a relatively small pool of CE manpower from which to select, and the mission dictates team size requirements. Through coordination of team training between the hub-and-spoke network units, (to include basic Prime BEEF training, team building, Silver Flag, and/or Combat Skills Training), there is a greater chance of influencing other factors such as team member ability. Two other compositional factors that the hub-and-spoke paradigm improves upon are member flexibility and preferences. As discussed further in the second overarching advantage of Localized Ownership, grouped leaders achieve greater control in adjusting when and for how long personnel are deployed, thus enabling greater flexibility to meet the needs of the mobility members. (Robins and Judge, 2007:pp346-351)

The third element of the Team Effectiveness Model, *work design*, includes characteristics that determine how motivated team members are in performing their duties; which in-turn effects overall team efficiency. While there is no

change in the workload or mission, when comparing two paradigms, the new alternative does change who is accomplishing the work. Specifically, the current method assigns various squadrons to fill various deployment requirements, such that one rotation may have one squadron's personnel filling positions at FOB A and FOB B, and then the next rotation filling positions at FOB C and FOB D. While this does increase the level of variety for the squadron, that is not the case for the individuals deploying. In actuality, it makes the UDM's job that much more difficult by forcing him or her to adjust deployment preparations to meet the differing mission needs. Conversely, the alternative ensures that across each rotation, any given squadron supports only one FOB. This not only eases the process for the UDM, by allowing for standardization in deployment preparations, but also enables individuals to better identify with their duties, whether through past deployments to that location or from feedback from other squadron members who went before them. (Robins and Judge, 2007:p351)

Lastly, the model's *process* element looks at how various characteristics effect team synergy and in-turn its effectiveness. Potential losses in team synergy can come from social loafers within the group, which is difficult to change given either alternative. Conflict between team members can provide both positive and negative effects, over which UDMs can have limited control during team formation. However, the establishment of a common purpose, specification of goals, and reinforcement of team efficacy, can help achieve positive synergy. Under the new alternative, civil engineers not only share the common purpose of

supporting a single FOB throughout its existence, but because of the regionalizing nature of hub-and-spoke networks, they may also share a common purpose within their region, such as improved mutual aid agreements for regional disaster response. Team efficacy, which equates to how well a team perceives its chances of success, also improves if hub-and-spoke partnered bases employ team-building opportunities during the pre-deployment phase, whether with the entire team or just key leadership positions. (Robins and Judge, 2007:pp351-353)

Mission Ownership

The second advantage of the hub-and-spoke alternative is that it creates a sense of mission ownership, such that the teamed-up CE squadrons have a greater control over the success and failure of the mission at their assigned FOB. By providing mission ownership, CE team members can provide *greater continuity* at the FOB leading to improved quality control and budgeting. It also creates an *invested interest* for team members to ensure that the work they do is of the highest standard. Mission ownership dampens the negative cyclic effects of *group development*, by forming semi-permanent groups. Lastly, it allows the team's *leadership planning* to be better and more flexible.

As discussed under the teaming advantage, the current process results in a single squadron serving multiple FOB locations throughout the cycles. Likewise, a large number of varying squadrons support a single FOB during a cycle. Because deployments lasting longer than six months have such a high negative impact on moral and fall under certain budgeting constraints, there are a limited

number of personnel, at any given FOB, who are capable of providing the detailed continuity necessary for complex projects and base development. Within the CE community, where mission-impacting construction often takes over six-months from design to completion, *continuity* plays a major role in quality control and remaining within budget. With mission ownership, personnel currently deployed, at both the leadership and shop levels, have a pre-established relationship with those that precede them and those scheduled to replace them. This connection should improve communication and thus *continuity* between deployment teams, each of which are composed of members from a single group. It is also likely that continuity would improve between BCEs and contractors that remain at the FOB.

Mission ownership also creates an *invested interest* for the personnel supporting the FOB. First, because of the fixed deployment location, individuals know that if they deploy more than once, they will return to the same FOB. This gives an individual purpose in that improvements made during the first deployment will benefit them later. Likewise, a lack of effort could make future deployments less enjoyable. Organizational behavior research cites physiological and safety characteristics such as these as low-order needs on Maslow's hierarchy of needs. Shown in Figure 2.4, Maslow's hierarchy of needs states that people seek fulfillment of lower order needs before higher order needs become key motivators. Therefore, physical and safety-related needs should prove to be good stimuli. A second source of invested interest, which results from this alternative, comes from the fact that the replacements for deployed individuals are friends and

co-workers that come from the deployed members own base. This means that their handiwork is subject to judgment by those that know them. Once again, Maslow's hierarchy of needs comes into play, only now the individual's actions impact social and esteem needs. Socially, they seek acceptance and belongingness with their co-workers. There are both internal and external factors that affect an individual's esteem including self-respect, achievement, status, and recognition. (Robins and Judge, 2007:p187)

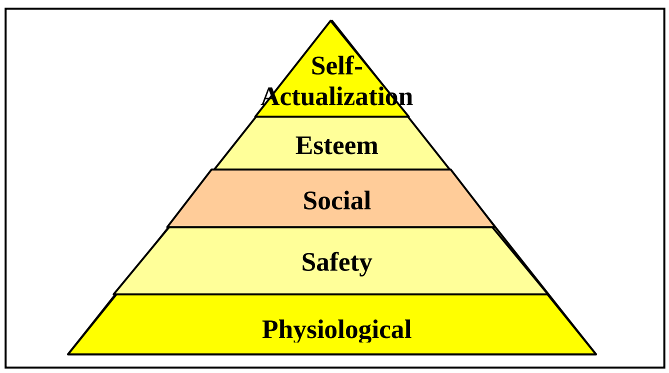


Figure 2.4 - Maslow's Hierarchy of Needs

Since home station bases need only to support one FOB, personnel at those bases remain in the group so long as reassignment to another base does not occur. Because of this, *group development* can begin between leadership and individual shops immediately following the hub-and-spoke network's formation. According to the five-stage model of group development, non-permanent work groups undergo five stages of development: 1) forming, 2) storming, 3) norming, 4) performing, and 5) adjourning. For permanent work groups, there is no need for the fifth step. Therefore, comparing the current AEF process with the hub-

and-spoke alternative is similar to comparing temporary to semi-permanent groups. As shown in Figure 2.5 below, the semi-permanent group model shows a distinct advantage in that more members of the group are able to remain in the performing stage of the model. Under the current AEF construct, each of the deployment iterations must undergo the forming, storming, and norming phases, which are generally attributed to lower performance and higher levels of conflict. (Robins and Judge, 2007:pp302-303)

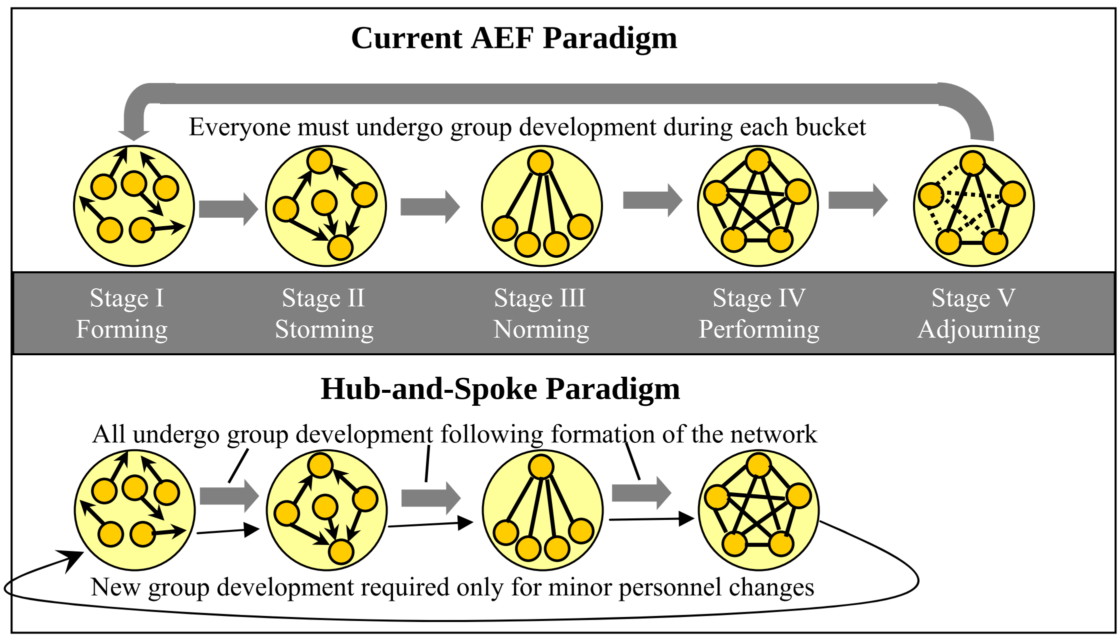


Figure 2.5 - A Comparison of the Stages of Group Development

A final characteristic of mission ownership is that it improves the effectiveness of CE *leadership planning*. Because the teamed leaders at a given FOB are the same leaders for the same personnel at home, they gain greater control over deployment lengths, departure dates, and team composition. This in-turn increases their ability to meet the needs and desires of their personnel. For

example, the team leaders could adjust deployment timelines or send Airmen home early to help address problems at home. Airmen who wish to deploy for longer than the standard tour length, often requested around reenlistment dates, would only need to make a local request. Incompatibility between team members is easier to address thanks to the increased flexibility given to local leaders; this in-turn reduces the stress felt by the team. All of these characteristics support the improvement of the team environment and satisfying individual needs. Work environment conditions and individual needs are both important factors in improving job satisfaction, which research has shown shares a strong correlation with job performance (Robins and Judge, 2007:pp87-90) Improved *leadership planning* also comes in the form of increasing the ability to forecast and ensure proper resources for future FOB needs. With semi-permanent leadership, the coordination process is easier, helping to address long-term planning and recommendations on what materials to ship with the next deploying bucket, thus ensuring the greatest level of success for everyone in the network.

Finally, the culmination of benefits which result from mission ownership improve upon almost all of Henri Fayol's 14 principals of management for projects, specifically: specialization of labor, authority, unity of command, unity of direction, centralization, chain of superiors, order, equity, personnel tenure, initiative, and *Esprit de corps*. (Fayol, 1916:pp19-42)

Minimized Change and Loss in Manpower

While both the current (AEF) and alternative (hub-and-spoke) options have no effective change in manpower levels at the FOB, the alternative option provides a key advantage when it comes to at-home manpower. This brings up the third major benefit of the alternative, which requires little justification by way of past research, that through the utilization of smaller teams, spread out over fewer buckets, units lose a smaller portion of their manpower at any given point in a cycle. Given that approximately 80% of the unit is susceptible to deploy during a given cycle, the current process may leave units only 60% manned during the two assigned buckets, where as this alternative ensures that units remain 80% manned over four buckets. Figure 2.6 below provides a graphical representation of this logic. As is shown, the current paradigm creates a pattern of constant change at the home stations throughout the cycle due to the roller-coaster effect on work force levels, as it pendulums between 100 and 60 percent manned. The hub-and-spoke paradigm, however, provides a much smoother pattern that creates fewer fluctuations in home stations manpower levels.

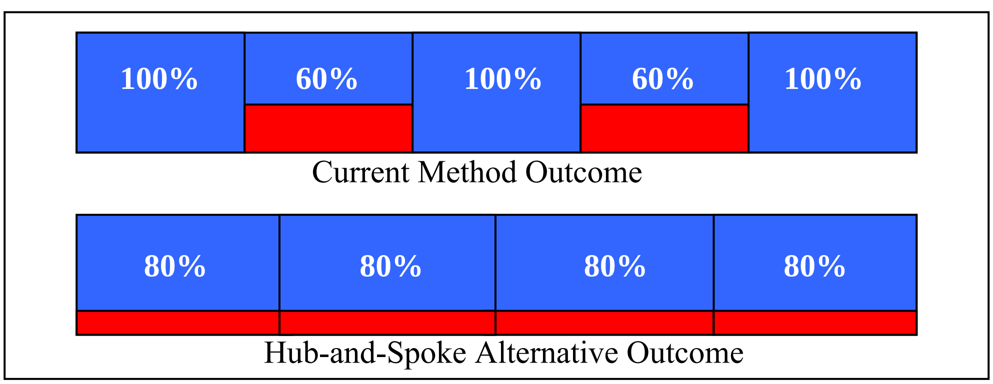


Figure 2.6 - CE Manpower; Current vs. Hub-and-Spoke Alternative

Diminished manpower levels equate to reduced resources, which drive an increase in individual workload that overall intensifies the stress levels within an organization. According to organizational change and stress management research, work stress can affect personnel physiologically, psychologically, and behaviorally. It also shows that while medium levels of stress can help to improve performance, high levels of stress can have an adverse affect on performance, as shown in Figure 2.7 below. (Robins and Judge, 2007:pp671-672)

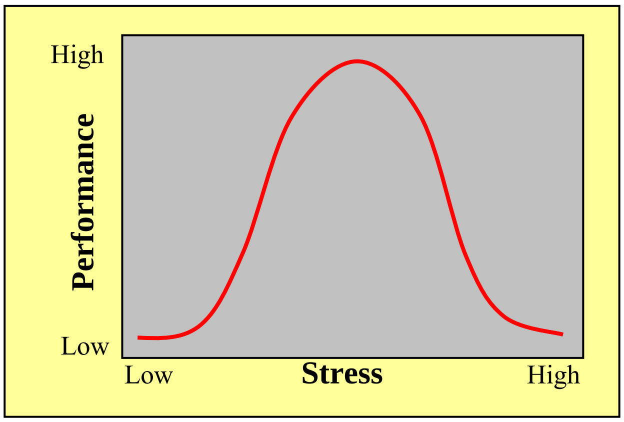


Figure 2.7 - Relationship Between Stress and Job Performance

2.5.2 Disadvantages

The hub-and-spoke network alternative also poses a number of concerns that are potential disadvantages when compared to the current AEF paradigm. Three potential disadvantages include: 1) the model's design focuses on addressing sustained operations, 2) hub-and-spoke networks have reduced flexibility, and 3) the model does not account for special deployment requirements, such as 365-day deployments.

Designed for Sustained Operations

The hub-and-spoke paradigm focuses on addressing issues arising out of sustained operations. Non-sustainment missions include those such as bare-base bed-down (build new), and redeployment (teardown) operations, which often require dynamic changes in personnel needs. Because hub-and-spoke networks rely on using a fixed manpower pool, it may not be flexible enough to address the varying mission requirements. However, if war planners could accurately predict and build teams capable of supporting the sustained operation before a bed-down commenced, and if the team's leadership was willing to operate under surge conditions, such as temporarily extending initial tour lengths, it may be possible to turn this into a positive situation. First, it could provide a more efficient, well planned, and well executed bed-down mission through the advantages of increased teamwork and ownership as addressed earlier. Furthermore, it could provide a greater level of ownership, as now the team is not only continually sustaining the FOB, but they also have a history with it as its architectural creator.

Reduced Flexibility

A second disadvantage associated with the alternative is the reduced level of flexibility. One of AEF's key benefits is that by using capabilities-based teams, called Unit Type Codes (UTC), it is easily adaptable to changing requirements. (Stewart, 2006:p17) Under a hub-and-spoke system, there are more ridged boundaries since team formation depends upon the mission, as the mission exists at one point in time. If a new FOB opens, there would need to be a

mechanism in place that either pulls squadrons from existing networks to meet the new requirement, or to have extra teams in reserve. Similarly, if an FOB closes, it poses the question of what to do with those supporting units. One option is to place the squadrons into reserve status; another is to redistribute the personnel to support other networks. The key to addressing this issue is ensuring war planners have good foresight into upcoming operational changes. For example, based on personal knowledge and experience, the Air Force has already labeled a handful of key installations as enduring bases, meaning the DoD plans on prolonged missions at these locations. Other FOBs have been identified for abandonment, tear-down, or to be put into a caretaker status to support potential conflicts in the future. Applying these known facts may help to determine if the use of hub-and-spoke networking would be useful at all or just a selected few FOBs.

Accounting for Special Taskings

A third minor disadvantage to this paradigm is that it does not account for special assignments including one-year deployments, non-traditional role augmentation, and taskings to FOBs outside of the model. As stated, this is only a minor disadvantage since, in comparison to the current paradigm, not much would need to change to use a hub-and-spoke method. Currently, based on personal knowledge and experience, meeting these requirements involves taxing each MAJCOM to fill a proportional number of positions. The alternative can utilize a similar policy by taxing hubs, or using the reserve team manpower pool created to address the issue of flexibility.

2.6 Multiple Objective Decision Analysis

"Decision analysis (DA) provides effective methods for organizing a complex problem into a structure that can be analyzed." DA researchers suggest using an iterative methodological approach when developing decision models, such as the DA process flow chart shown in Figure 2.8 below. (Clemens and Riley, 2001:pp2 and 6)

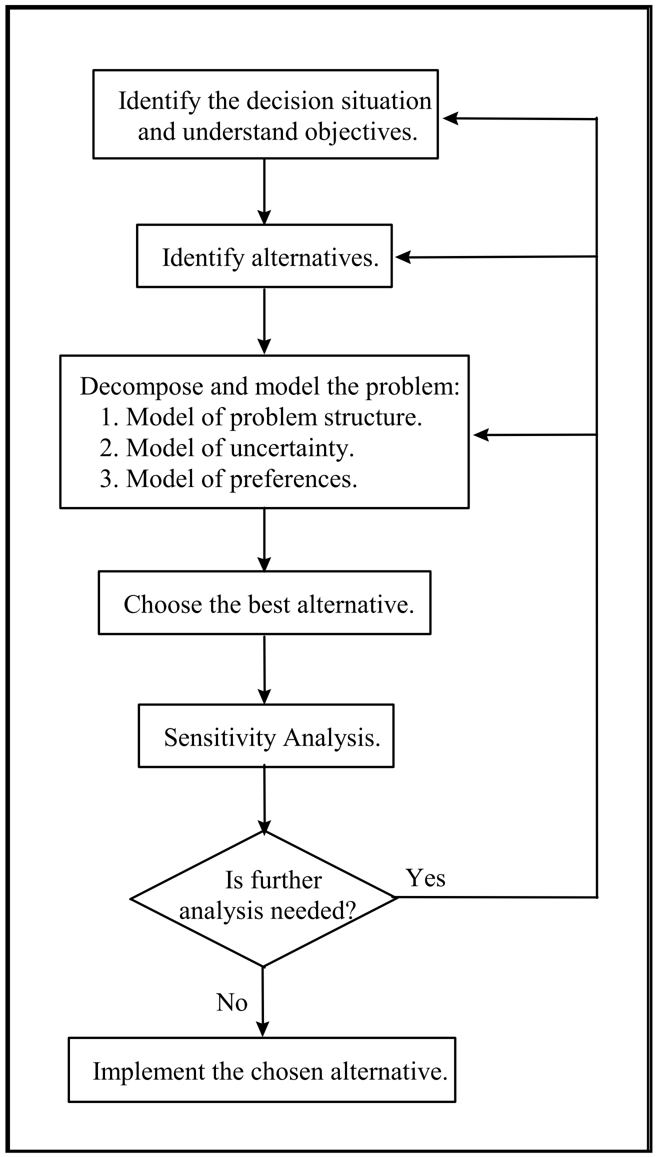


Figure 2.8 - Decision-Analysis Process Flowchart

The first step is to identify the decision and its objectives. The primary driving objective is to determine the best means of deploying CE Prime BEEF personnel. However, this research focuses on a single alternative to that decision, by investigating how optimally grouped Air Force bases can meet CE deployment needs, while maximizing the value earned in five conflicting objectives, as defined in Chapter 3. Specifically, this model evaluates 2^{1872}, or 3.374E+563, combinations based on binary variables alone. The actual number of combinations is much larger due to the 24 non-binary variables that represent objective minimums.

Next, modeling the problem means recognizing what type of model best fits the situation. As discussed earlier in Section 2.3, the characterization of network flow problems is that they are best described or displayed in graphical form, they have a goal of determining how many items (i.e. deployers) should be moved within the network, and are constrained by balance-of-flows rules, which ensure that supply and demand needs are being met. (Ragsdale, 2007:pp177-180) Chapter 3 provides additional details on how network flow problems, and more specifically hub-and-spoke networks, help in solving this problem. Uncertainty plays a small role in the model in that the weighting of objectives could affect the best solution.

The forth, fifth, and sixth steps are addressed in Chapter 4, but essentially help to prove or disprove whether or not the model works. Lastly, while it is not possible to accomplish the implementation step in this research, Chapter 5 does provide recommendations, based on the results of the model, for consideration by Air Force Headquarters CE staff members.

2.7 Premium Frontline Solver

Frontline's Premium edition Solver, an add-in to Microsoft Excel, provides the necessary computing power to tackle this complex mixed-integer LP. Specifically, it is capable of handling up to 8000 variables, 2000 integer variables (including binary), and 8000 constraints. The premium edition works similarly to the basic solver package, allowing the user to define the objective function cell (set cell), whether to maximize or minimize the set cell, define variable cells, and define constraints.

2.8 Summary

This chapter reviewed the past and present of CE and Air Force deployments, providing a clear understanding of the lessons learned and challenges faced by current leaders. It also reviewed network flow problems and hub-and-spoke networks. Then the chapter explained the advantages and disadvantages of this new alternative, including applicable organizational behavior research, which includes the benefits of groups and teaming. Next discussed were the major elements of decision analysis that the methodology employs in this research. Finally, it provided a brief look at the Frontline Premium Solver software that is used. Chapter 3 discusses how all of the elements from Chapter 2 tie together in the problem's model and its optimization.

3. METHODOLOGY

3.1 Chapter Overview

Chapter 3 provides a detailed explanation of how the hub-and-spoke paradigm is tested using a multi-objective mixed-integer LP model. First discussed is the model's development, which includes the general nature of hub-and-spoke networks, and their usefulness in addressing this problem. Also explained are the objectives and constraints that factor into the model. The next section details the model's physical creation. As Chapter 2 explains, this model employs the Frontline Premium Solver add-in for Microsoft Excel. This section and Appendix D provide screenshots of the model and explanations of the variables, constraints, and the objective function. Figure D.1 summarizes the model tabs, and includes a legend for color-coding. Finally, this chapter looks at the objective weights, including the logic used in establishing their values.

3.2 Developing the Model

This section reviews the basic principals behind this model's development including the application of hub-and-spoke networks to the problem, definition of the decision variables, explanation of the objectives, and development of the constraints.

3.2.1 Applying Hub-and-Spoke Networking to the Problem

As discussed in Chapter 2, to build a hub-and-spoke network, one must first identify the nodes. In this model, supply nodes are any one of the 39 CONUS bases or base-combinations identified within the scoping limitations. These nodes serve as the spokes. Additionally all 39 bases serve as potential transshipment nodes, hereafter identified as hubs. Lastly, the demand nodes in the model represent the FOBs, to which

the hubs supply personnel. Figure 3.1 provides a graphical representation of the model. The left set of nodes in the model, labeled S_1 through S_n, represent the 39 bases that serve as spokes in the solution. The second set of nodes, H_1 through H_n, again represent the 39 bases; however, this time they are only considered as a potential hub in the network. That is, the solution does not use every hub node, as the number of hubs used must be equal to the number of FOBs in the model. The arcs connecting the spokes to the hubs represent costs with respect to the problem's objectives, as is discussed later in this section. Whenever an arc ties a spoke to a hub from the same base, that arc essentially has a cost of zero. In instances where the bases differ, the arc costs factor into the computation of the objective function. The demand nodes, identified as F_1 through F_m, represent the nine FOBs or FOB-pairs, considered in the problem, and similarly have arcs connecting them to the hubs, each of which have an associated cost.

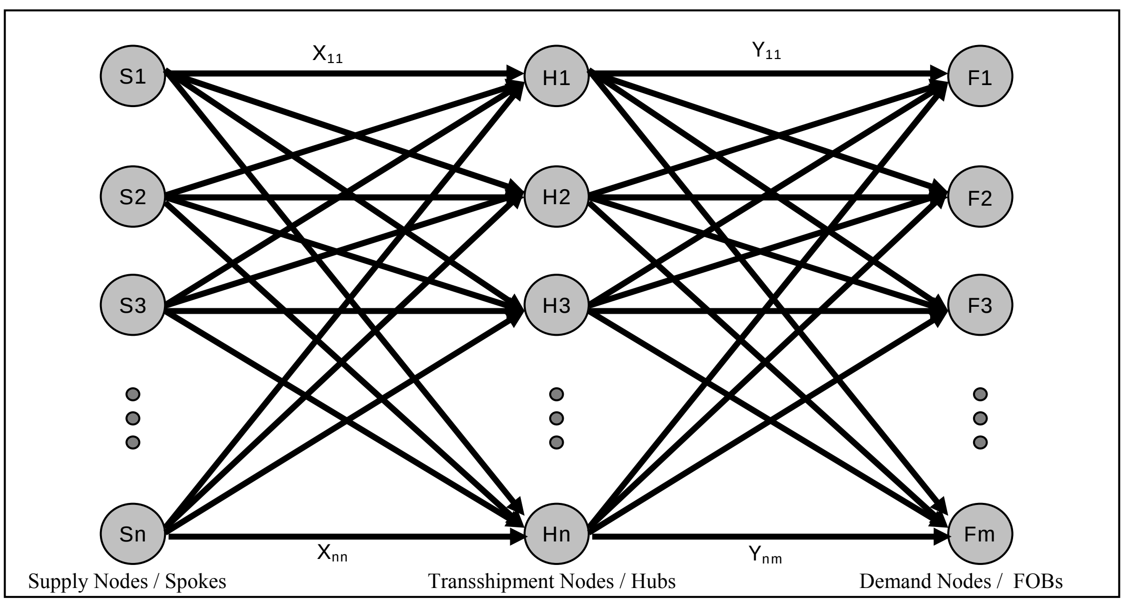


Figure 3.1 - Basic Hub-and-Spoke Model

3.2.2 Defining the Decision Variables

Each arc in the above model has one decision variable associated with it that identifies whether or not the arc is used. For this problem, the links between spokes and hubs either do or do not exist. The same is true for the link between Hubs and FOBs. For this reason, all variables in the model are purely binary, where the value of one indicates that the arc is used and zero indicates that it is not used. Variables for Spoke-Hub links are X_{SH}, where S is the respectively numbered Spoke, and H is the respectively numbered Hub, both of which range from one to 39. Variables for Hub-FOB links are Y_{HF}, where H is the respectively numbered Hub, ranging from one to 39, and F is the respectively numbered FOB, ranging from one to nine.

3.2.3 Defining Multiple Objectives within the Model

There are five model objectives: 1) distance, 2) manpower, 3) mission matching, 4) airlift, and 5) weather. This section looks at each and explains the value gained by its inclusion in the model. This chapter includes a discussion of weighting each objective.

Distance

First, the model is interested in minimizing the travel distances, as one of the benefits of hub-and-spoke networks, as explained in Chapter 2, is that the proximity of bases can allow for joint training and exercises, consolidated equipment, and ease of departure for deployments. Table 3.1 below, provides a summary of distances between each of the bases. (Source: Defense table of Official Distances, dtod.sddc.army.mil, Aug 2007)

Table 3.1 - Base Distances

Spoke \ Hub	Altus	Andrews	Barksdale	Beale	Bolling	Cannon	Charleston	Davis-Monthan	Dover	Dyess	Ellsworth	Fairchild	FE Warren	Grand Forks	Holloman	Hurlburt Fld/(Tyndall)	Lackland	Langley	Little Rock	Luke	Malmstrom	McChord	McConnell	McGuire	Minot	Moody	Mt Home	Nellis	Patrick	Peterson	Robins	Scott	Seymour Johnson	Shaw	Sheppard	Tinker	Travis	Vandenberg	Whiteman
Altus		1485	421	1593	1480	290	1290	916	1550	189	864	1726	726	1094	544	961	410	1493	473	942	1389	1987	296	1559	1256	1209	1418	1048	1421	557	1081	659	1401	1229	88	145	1580	1409	541
Andrews	1485		1205	2745	12	1715	535	2298	95	1545	1621	2513	1651	1443	1967	982	1626	180	1031	2366	2142	2814	1271	167	1635	742	2356	2418	885	1661	702	832	288	460	1485	1349	2776	2834	1039
Barksdale	421	1205		2066	1199	642	901	1142	1294	388	1256	2166	1167	1240	795	492	469	1190	233	1282	1830	2428	554	1364	1432	819	1858	1515	951	1053	692	643	1036	839	340	405	2027	1788	556
Beale	1593	2745	2066		2737	1350	2827	925	2817	1683	1392	919	1095	1774	1241	2533	1780	2873	2012	796	1110	704	1701	2826	1537	2759	565	614	3005	1264	2632	2002	2857	2760	1627	1671	92	407	1807
Bolling	1480	12	1199	2737		1709	534	2292	99	1539	1613	2506	1643	1435	1962	977	1620	175	1026	2361	2134	2805	1267	176	1627	736	2348	2410	879	1657	697	825	283	454	1480	1343	2770	2827	1030
Cannon	290	1715	642	1350	1709		1520	561	1773	259	917	1600	601	1318	234	1181	493	1721	702	691	1264	1712	520	1782	1297	1438	1143	798	1642	431	1312	884	1630	1459	297	369	1322	1158	766
Charleston	1290	535	901	2827	534	1520		2041	628	1287	1797	2706	1733	1635	1694	566	1301	444	842	2181	2334	3012	1294	708	1827	263	2438	2278	407	1684	262	832	281	105	1239	1154	2802	2638	1055
Davis-Monthan	916	2298	1142	925	2292	561	2041		2387	759	1311	1507	994	1926	329	1621	868	2305	1286	141	1349	1584	1146	2451	1690	1852	1078	417	2081	825	1831	1510	2175	1979	916	995	885	647	1391
Dover	1550	95	1294	2817	99	1773	628	2387		1634	1693	2585	1723	1515	2028	1075	1715	207	1120	2427	2214	2885	1342	119	1707	835	2428	2490	978	1733	795	904	381	553	1550	1438	2850	2893	1110
Dyess	189	1545	388	1683	1539	259	1287	759	1634		1003	1822	823	1313	413	928	272	1551	533	900	1486	2083	515	1698	1505	1159	1514	1133	1388	653	1078	879	1422	1225	163	365	1643	1406	761
Ellsworth	864	1621	1256	1392	1613	917	1797	1311	1693	1003		937	330	651	977	1710	1929	1775	1133	1336	601	1238	734	1702	463	1730	870	1126	1999	499	1603	972	1772	1735	1021	889	1425	1554	777
Fairchild	1726	2513	2166	919	2506	1600	2706	1507	2585	1822	937		1014	1241	1660	2632	2245	2667	2065	1425	418	311	1621	2606	1005	2657	472	1034	2926	1183	2531	1900	2664	2644	1907	1775	936	1251	1704
FE Warren	726	1651	1167	1095	1643	601	1733	994	1723	823	330	1014		990	660	1645	1245	1779	1066	1020	678	1275	621	1732	710	1665	706	840	1935	184	1539	908	1763	1666	908	775	1128	1269	713
Grand Forks	1094	1443	1240	1774	1435	1318	1635	1926	1515	1313	651	1241	990		1572	1655	1432	1597	1116	1951	870	1542	803	1524	215	1674	1273	1649	1944	1115	1549	943	1594	1568	1094	962	1808	2078	761
Holloman	544	1967	795	1241	1962	234	1694	329	2028	413	977	1660	660	1572		1396	643	1975	955	469	1324	1689	773	2037	1357	1627	1120	745	1856	492	1485	1137	1828	1632	507	622	1214	975	1018
Hurlburt Fld/(Tyndall)	961	982	492	2533	977	1181	566	1621	1075	928	1710	2632	1645	1655	1396		767	954	553	1761	2300	2932	1094	1148	1847	254	2398	2054	483	1593	349	745	787	615	879	944	2505	2267	968
Lackland	410	1626	469	1780	1620	493	1301	868	1715	272	1929	2245	1245	1432	643	767		1595	614	1008	1909	2451	633	1779	1624	998	1723	1283	1227	887	1012	997	1434	1239	397	483	1752	1514	878
Langley	1493	180	1190	2873	175	1721	444	2305	207	1551	1775	2667	1779	1597	1975	954	1595		1037	2372	2296	2968	1333	346	1789	650	2484	2481	794	1724	612	877	198	369	1492	1356	2904	2839	1102
Little Rock	473	1031	233	2012	1026	702	842	1286	1120	533	1133	2065	1066	1116	955	553	614	1037		1354	1729	2326	453	1190	1308	756	1757	1460	1024	952	628	430	946	775	472	336	1984	1820	349
Luke	942	2366	1282	796	2361	691	2181	141	2427	900	1336	1425	1020	1951	469	1761	1008	2372	1354		1268	1455	1172	2434	1716	1992	997	279	2221	851	1972	1536	2281	2119	976	1020	757	518	1417
Malmstrom	1389	2142	1830	1110	2134	1264	2334	1349	2214	1486	601	418	678	870	1324	2300	1909	2296	1729	1268		718	1284	2223	557	2320	610	986	2590	847	2194	1563	2293	2267	1571	1439	1144	1414	1368
McChord	1987	2814	2428	704	2805	1712	3012	1584	2885	2083	1238	311	1275	1542	1689	2932	2451	2968	2326	1455	718		1881	2906	1305	2959	589	1285	3226	1444	2831	2200	2965	2944	2169	2036	721	1036	2005
McConnell	296	1271	554	1701	1267	520	1294	1146	1342	515	734	1621	621	803	773	1094	633	1333	453	1172	1284	1881		1351	994	1223	1312	1263	1493	507	1095	464	1320	1226	295	163	1735	1639	250
McGuire	1559	167	1364	2826	176	1782	708	2451	119	1698	1702	2606	1732	1524	2037	1148	1779	346	1190	2434	2223	2906	1351		1716	914	2437	2499	1058	1742	868	913	454	626	1559	1426	2859	2902	1119
Minot	1256	1635	1432	1537	1627	1297	1827	1690	1707	1505	463	1005	710	215	1357	1847	1624	1789	1308	1716	557	1305	994	1716		1866	1036	1412	2136	880	1740	1864	1786	1760	1286	1153	1571	1841	953
Moody	1209	742	819	2759	736	1438	263	1852	835	1159	1730	2657	1665	1674	1627	254	998	650	756	1992	2320	2959	1223	914	1866		2370	2196	287	1613	142	764	487	312	1111	1072	2737	2499	987
Mt Home	1418	2356	1858	565	2348	1143	2438	1078	2428	1514	870	472	706	1273	1120	2398	1723	2484	1757	997	610	589	1312	2437	1036	2370		582	2640	875	2244	1613	2468	2371	1600	1467	598	913	1418
Nellis	1048	2418	1515	614	2410	798	2278	417	2490	1133	1126	1034	840	1649	745	2054	1283	2481	1460	279	986	1285	1263	2499	1412	2196	582		2466	815	2070	1610	2388	2216	1083	1127	601	430	1410
Patrick	1421	885	951	3005	879	1642	407	2081	978	1388	1999	2926	1935	1944	1856	483	1227	794	1024	2221	2590	3226	1493	1058	2136	287	2640	2466		1873	412	1034	631	455	1339	1342	2966	2727	1257
Peterson	557	1661	1053	1264	1657	431	1684	825	1733	653	499	1183	184	1115	492	1593	887	1724	952	851	847	1444	507	1742	880	1613	875	815	1873		1485	854	1710	1617	591	662	1297	1244	655
Robins	1081	702	692	2632	697	1312	262	1831	795	1078	1603	2531	1539	1549	1485	349	1012	612	628	1972	2194	2831	1095	868	1740	142	2244	2070	412	1485		639	448	253	1028	945	2601	2430	861
Scott	659	832	643	2002	825	884	832	1510	904	879	972	1900	908	943	1137	745	997	877	430	1536	1563	2200	464	913	1864	764	1613	1610	1034	854	639		863	770	659	527	2035	2003	230
Seymour Johnson	1401	288	1036	2857	283	1630	281	2175	381	1422	1772	2664	1763	1594	1828	787	1434	198	946	2281	2293	2965	1320	454	1786	487	2468	2388	631	1710	448	863		206	1372	1264	2891	2748	1086
Shaw	1229	460	839	2760	454	1459	105	1979	553	1225	1735	2644	1666	1568	1632	615	1239	369	775	2119	2267	2944	1226	626	1760	312	2371	2216	455	1617	253	770	206		1177	1092	2748	2577	988
Sheppard	88	1485	340	1627	1480	297	1239	916	1550	163	1021	1907	908	1094	507	879	397	1492	472	976	1571	2169	295	1559	1286	1111	1600	1083	1339	591	1028	659	1372	1177		145	1615	1444	540
Tinker	145	1349	405	1671	1343	369	1154	995	1438	365	889	1775	775	962	622	944	483	1356	336	1020	1439	2036	163	1426	1153	1072	1467	1127	1342	662	945	527	1264	1092	145		1658	1487	408
Travis	1580	2776	2027	92	2770	1322	2802	885	2850	1643	1425	936	1128	1808	1214	2505	1752	2904	1984	757	1144	721	1735	2859	1571	2737	598	601	2966	1297	2601	2035	2891	2748	1615	1658		318	1840
Vandenberg	1409	2834	1788	407	2827	1158	2638	647	2893	1406	1554	1251	1269	2078	975	2267	1514	2839	1820	518	1414	1036	1639	2902	1841	2499	913	430	2727	1244	2430	2003	2748	2577	1444	1487	318		1840
Whiteman	541	1039	556	1807	1030	766	1055	1391	1110	761	777	1704	713	761	1018	968	878	1102	349	1417	1368	2005	250	1119	953	987	1418	1410	1257	655	861	230	1086	988	540	408	1840	1840	

Manpower

As discussed earlier, constraints in the model ensure that the supply is greater-than-or-equal-to the demand. In reality, each FOB's demand is variable and depends on changing missions. To ensure the greatest flexibility, and to account for non-deployable personnel, it is important to have a work force surplus. One major real-world factor, not in the model, is the use of guard and reserve personnel. This research assumes an equal distribution of these resources among the hubs when applying this paradigm. Therefore, the true manpower surplus is greater than that reflected in this model's calculation. Tables 3.2 and 3.3 summarize the FOB requirements and home-station base (Spoke) resources.

Table 3.2– FOB Requirements and Missions

																	Mission Data (1=mission at location, 0=otherwise)							
FOB Name	Officers	Chief	Superintendent	First Sergeant	Supply	Electrical	Power Pro	HVAC/R	Pavements	Structural	Utilities	Liquid Fuels	Pest Mgt	Engineering	Operations Mgt	Bucket TOTAL	Primary Mission	KC-135	KC-10	C130	C17	F15	F16	A10
Al Udeid	10	1	4	1	6	32	10	36	32	29	34	0	2	14	6	217	KC135, KC10, F15, C130	1	1	1	0	1	0	0
Al Dhafra	3	1	3	1	2	10	7	9	8	7	8	2	2	3	2	68	KC10	0	1	0	0	0	0	0
Ali Al Salem	7	2	4	1	2	8	16	12	8	8	10	2	2	8	3	93	C130	0	0	1	0	0	0	0
Balad	6	1	5	1	4	15	22	15	16	12	18	2	2	5	4	128	F16, A10, C130	0	0	1	0	0	1	1
Ali Base	4	1	5	1	2	8	16	9	12	7	9	0	2	3	2	81	C130	0	0	1	0	0	0	0
Kirkuk	6	1	4	1	2	8	4	9	8	8	13	0	2	5	3	74	No Fixed AC	0	0	0	0	0	0	0
Bagram/Kandahar	2	0	0	0	2	5	6	0	20	5	0	0	0	4	0	44	A10, F15, C130	0	0	1	0	1	0	1
Manas	5	1	4	1	2	7	2	9	8	10	8	0	2	3	2	64	KC135, C17	1	0	0	1	0	0	0
BIAP/Sather	4	1	3	1	2	7	12	9	8	7	8	2	2	3	2	71	C130, C17	0	0	1	1	0	0	0
EMPTY FOB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
Bucket TOTAL	47	9	32	8	24	100	95	108	120	93	108	8	16	48	24	840		2	2	6	2	2	1	2

Note: Manpower data from Supplement to CE Traditional Ops UTC Transformation Brief Mission data from web data on GlobalSecuirty.org (as of Sept 07)

Table 3.3 – Summary of Home-Station Base

Base Name	Power Pro	HVAC/R	Pavements	Structural	Utilities	Liquid Fuels	Pest Mgt	Engineering	Operations Mgt	TOTAL	Mission Data (1=mission at location, 0=otherwise) Summary and Notes	KC-135	KC-10	C130	C17	F15	F16	A10	Air Lift? (1=Y, 0=N)	Cold Wx? (1=Y, 0=N)
Altus	6	11	18	12	11	4	1	7	2	100	AETC (C5,C17,KC135)	1	0	0	1	0	0	0	0	0
Andrews	28	27	23	24	32	6	3	11	6	214	AFRC (KC135), ANG (F16)	1	0	0	0	0	1	0	1	0
Barksdale	12	15	17	17	20	5	4	8	4	141	AFRC (A10,B52), ACC (B52)	0	0	0	0	0	0	1	0	0
Beale	27	36	19	17	18	5	2	13	4	181	AFRC (KC135)	1	0	0	0	0	0	0	1	0
Bolling	9	9	25	11	11	0	4	16	2	132	AF Band??	0	0	0	0	0	0	0	0	0
Cannon	15	13	19	17	21	4	3	7	5	138	ACC (F16)	0	0	0	0	0	1	0	0	0
Charleston	8	15	15	15	20	4	3	9	4	125	AFRC (C17), AMC (C17)	0	0	0	1	0	0	0	1	0
Davis-Monthan	27	28	18	19	20	4	3	11	5	182	ACC (A10)	0	0	0	0	0	0	1	0	0
Dover	10	13	15	30	24	3	4	10	2	150	AFRC (C5), AMC (C5)	0	0	0	0	0	0	0	1	0
Dyess	10	22	21	18	23	6	3	12	5	154	ACC (B1), AMC (C130)	0	0	1	0	0	0	0	1	0
Ellsworth	17	27	29	28	29	7	4	21	6	221	ACC (B1)	0	0	0	0	0	0	0	0	0
Fairchild	10	11	21	17	19	4	3	10	5	136	ANG (KC135), AMC (KC135)	1	0	0	0	0	0	0	1	1
FE Warren	11	18	19	15	18	3	3	6	3	133	Space Base	0	0	0	0	0	0	0	0	1
Grand Forks	15	15	17	16	27	6	4	8	4	159	AMC (KC135)	1	0	0	0	0	0	0	1	1
Holloman	55	65	30	59	48	4	5	13	9	362	ACC (F117)	0	0	0	0	0	0	0	0	0
Hurlburt Fld/(Tyndall)	24	23	18	20	24	5	3	26	3	231	AETC(TAFB) (F15), AFSOC (C-130)	0	0	1	0	1	0	0	0	0
Lackland	0	10	0	18	1	0	0	7	10	79	AFRC (C5), ANG (F16)	0	0	0	0	0	1	0	1	0
Langley	30	48	27	25	28	4	4	13	5	235	AFRC (F15,F16, A10), ACC (F15,F22)	0	0	0	0	1	1	1	0	0
Little Rock	8	15	13	21	15	4	2	11	4	122	AETC(AD&ANG) (C130), AMC (C130)	0	0	1	0	0	0	0	1	0
Luke	12	16	12	17	21	0	4	7	3	122	AFRC (F16), AETC (F16)	0	0	0	0	0	1	0	0	0
Malmstrom	13	17	32	25	21	3	4	13	4	174	Space Base	0	0	0	0	0	0	0	0	1
McChord	9	13	14	21	16	4	2	8	3	122	AFRC (C17), AMC (C17)	0	0	0	1	0	0	0	1	0
McConnell	9	11	12	12	14	4	2	8	4	115	AFRC (KC135), ANG (KC135), AMC (KC135)	1	0	0	0	0	0	0	1	0
McGuire	15	19	20	18	21	5	3	12	4	164	AFRC (KC10,C17), AMC (KC10,C17)	0	1	0	1	0	0	0	1	0
Minot	18	34	32	36	32	4	4	22	6	242	ACC (B52)	0	0	0	0	0	0	0	0	1
Moody	11	12	16	13	18	3	2	11	4	119	ACC (A10)	0	0	0	0	0	0	1	0	0
Mt Home	9	20	19	14	20	3	2	7	5	134	ACC (F15,F16)	0	0	0	0	1	1	0	0	1
Nellis	24	41	29	33	33	5	7	19	6	252	ACC (A10,F15,F16)	0	0	0	0	1	1	1	0	0
Patrick	13	14	14	16	15	2	2	10	0	115	AFRC (C130)	0	0	1	0	0	0	0	1	0
Peterson/(Schriever/Buckley	13	15	24	29	21	5	4	17	7	198	AFRC (C130), ANG (F16)	0	0	1	0	0	1	0	1	1
Robins	45	21	0	0	0	0	0	2	1	81	AFMC (C5,C130,F15,C17), AMC (KC135)	1	0	1	1	1	0	0	1	0
Scott	11	24	15	16	22	4	4	14	3	155	ANG (KC135)	1	0	0	0	0	0	0	1	0
Seymour Johnson	15	17	23	23	25	4	6	13	5	169	AFRC (KC135), ACC (F15)	1	0	0	0	1	0	0	1	0
Shaw	38	42	28	17	24	4	4	13	4	227	ACC (F16)	0	0	0	0	0	1	0	0	0
Sheppard	15	18	1	1	9	7	4	0	5	93	AETC	0	0	0	0	0	0	0	0	0
Tinker	44	22	0	0	0	0	0	1	0	71	AFRC (KC135), AFMC ((B1,B52,KC135,KC10)	1	1	0	0	0	0	0	1	0
Travis	29	35	25	24	27	11	2	12	5	243	AFRC (C5,C17,KC10), AMC (C5,KC10,C17)	0	1	0	1	0	0	0	1	0
Vandenberg	24	16	39	18	29	2	1	12	0	198	Space Base	0	0	0	0	0	0	0	0	0
Whiteman	16	20	21	23	29	7	3	11	5	177	AFRC (A10), ACC (B2)	0	0	0	0	0	0	1	0	0
TOTAL	705	848	740	755	806	155	118	431	162			10	3	6	6	6	9	6	19	7

Note: Manpower data from Blue Suit Review data; Mision/Airlift data from Airman Magazine, Jan 07; Weather data based on bases annual snowfall

Mission Matching

Each home-station base has one or more defined missions, such as air refueling with KC-135s, aerial attack with F-16, and so on. Similarly, FOBs also have one or more defined missions. This objective looks to maximize the number of home-station bases that shares one or more missions with the FOB it supports. By doing so, the home-station personnel will have an advantage due to their pre-established understanding of the mission. Tables 3.2 and 3.3 summarize the missions.

Airlift

A second important objective for the model is to ensure that each network has a minimum airlift capability; either from the hub base or one of the associated spokes. This objective could make traveling easier and less expensive for both deployments and off-site training. Table 3.3 summarizes airlift capabilities.

Weather

It is important to consider weather matching between the networked bases and the FOB they support. One FOB in particular, Manas, faces severe winter weather, and, as such, has many unique challenges including mission critical heating requirements, plumbing winterization, cold weather design, and snow removal. Having experience with these issues increases the FOBs chances for success. For this reason, the model includes an objective to maximize the number of cold-weather home-station bases that support Manas Air Base (AB). Table 3.3 summarizes home-station weather climates.

3.2.4 Defining Model Constraints

There are a number modeling constraints that are necessary in determining the best solution. As noted earlier, the majority of the decision variables are constrained as binary. Additionally, each base must support one and only one hub-and-spoke network, and each hub-and-spoke network must support one and only one FOB. As such, the total number of hub-and-spoke networks created must equal the number of FOBs in the model. The following sections discuss the modeling constraints in more detail.

3.3 Formulating and Building the Model

This section explains the actual equations and modeling techniques applied in the model. First, it looks at the model's core or foundation, which includes construction of the decision variable matrices as well as constraints essential to finding the best feasible solution. Next, the section explains the modeling procedures used to address the five objectives.

3.3.1 The Model's Core

The first step in building such a complex model was to design its core. The key to this is having a clear understanding of the primary decision variables (DV) and the two matrices that capture them in the model. As defined earlier, every potential Spoke-Hub combination requires a DV, denoted as X_{SH}, where:

$$X_{SH} = \begin{cases} 1 & \text{If base } S \text{ is a spoke to the hub at base } H \\ 0 & \text{Otherwise} \end{cases}$$

Representing these DVs in the model is a 39 x 39 binary matrix, which lists base names along each axis. The y-axis indicates each base as a potential spoke, while the x-axis represents each base as a potential hub. Figures 3.2 and D.2 show this matrix.

The 39 instances of where the base names match up on both the x-and y-axis indicate hub DVs. Cells at the bottom of the matrix, linked to the hub DVs, sum up the total number of hubs, and ensure that it is equal to the total number of FOBs using:

$$\left(\sum_{H=1}^{n} X_{HH} \right) - (m) = 0 ,$$

Where n = number of home-station bases in the model,
m = number of FOBs in the model,
$X_{HH} = X_{SH}$ DVs where $S = H$ (i.e. a hub DV)

A column along the right side of the matrix provides a sum of the spoke-hub DVs for each of the spoke bases. By constraining each sum to equal one, the model ensures the assignment of each base to one and only one hub; or as formulated:

$$\sum_{H=1}^{n} X_{SH} = 1 ,$$

For all values of S (1 thru n)
Where n = number of home-station bases in the model,
X_{SH} = Hub-Spoke DV

In any instance where a spoke-hub DV is equal to one, the hub in that combination must also have its hub DV set equal to one. To ensure this, a linking constraint is necessary. A row along the bottom of the matrix provides a sum of the spoke-hub DVs for each of the hub bases. The linking constraint, which must be less than or equal to zero, multiplies each hub indicator's binary DV by 60 and subtracts that from the respective spoke-hub sums; or as formulated:

$$\left(\sum_{S=1}^{n} X_{SH} \right) - (60 * X_{HH}) \leq 0 ,$$

For all values of H (1 thru n)
Where n = number of home-station bases in the model,
X_{SH} = Spoke-Hub DV,
$X_{HH} = X_{SH}$ DVs where $S = H$ (i.e. a hub DV)

Hub / Spoke	Altus	Andrews	Barksdale	Beale	Bolling	Cannon	Charleston	Davis-Monthan	Dover	Dyess	Ellsworth	Fairchild	FE Warren	Grand Forks	Holloman	Hurlburt Fld/(Tyndall	Lackland	Langley	Little Rock	Luke	Malmstrom	McChord	McConnell	McGuire	Minot	Moody	Mt Home	Nellis	Patrick	Peterson/(Schriever	Robins	Scott	Seymour Johnson	Shaw	Sheppard	Tinker	Travis	Vandenberg	Whiteman	Assignment Totals
Altus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Andrews	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Barksdale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Beale	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Bolling	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Cannon	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Charleston	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Davis-Monthan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Dover	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Dyess	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Ellsworth	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Fairchild	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
FE Warren	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Grand Forks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Holloman	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Hurlburt Fld/(Tynda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Lackland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Langley	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Little Rock	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Luke	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Malmstrom	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
McChord	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
McConnell	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
McGuire	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Minot	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Moody	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Mt Home	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Nellis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Patrick	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Peterson/(Schrieve	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Robins	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Scott	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Seymour Johnson	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Shaw	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Sheppard	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Tinker	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Travis	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Vandenberg	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Whiteman	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Totals	0	0	0	0	4	7	0	0	4	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	5	3	0	3	6	0	0	0	0	
Linking Constraint	0	0	0	0	-56	-53	0	0	-56	0	0	-56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-57	-55	-57	0	-57	-54	0	0	0	0	
A Hub? Binary	0	0	0	0	1	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	0	0	0	0	

# Hubs	# FOBs
9	9

Figure 3.2 - Spoke-Hub Matrix

Similar to spoke-hub combinations, every potential Hub-FOB combination also requires a decision variable, denoted as Y_{HF}, where:

$$Y_{HF} = \begin{cases} 1 & \text{If base } H \text{ is the hub that supports FOB } F \\ 0 & \text{Otherwise} \end{cases}$$

Representing these DVs in the model is a 9 x 39 binary matrix, which lists Hub base names along the y-axis (horizontal), and FOB names along x-axis (vertical). Each cell represents a potential Hub-FOB combination. Figures 3.3 and D.2 show this matrix.

Hub / FOB	Altus	Andrews	Barksdale	Beale	Bolling	Cannon	Charleston	Davis-Monthan	Dover	Dyess	Ellsworth	Fairchild	FE Warren	Grand Forks	Holloman	Hurlburt Fld/(Tyndall)	Lackland	Langley	Little Rock	Luke	Malmstrom	McChord	McConnell	McGuire	Minot	Moody	Mt Home	Nellis	Patrick	Peterson/(Schriever/Buckley)	Robins	Scott	Seymour Johnson	Shaw	Sheppard	Tinker	Travis	Vandenberg	Whiteman	Group Totals
Al Udeid	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Al Dhafra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Ali Al Salem	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Balad	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Ali Base	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Kirkuk	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Bagram/Kandahar	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Manas	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
BIAP/Sather	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
EMPTY FOB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hub Totals 2	0	0	0	0	1	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	0	0	0	0	9
Hub Totals 1	0	0	0	0	1	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	0	0	0	0	9

Figure 3.3 - Hub-FOB Matrix

A column along the right side of this matrix provides a sum of the hub-FOB DVs for each of the FOBs. By constraining each sum to equal one, the model ensures the assignment of each FOB to one and only one hub; or as formulated:

$$\sum_{F=1}^{m} Y_{HF} = 1,$$

For all values of H (1 thru n)
Where n = number of home-station bases in the model,
m = number of FOBs in the model,
Y_{HF} = Hub-FOB DV

In any instance where a hub DV equals one in the spoke-hub matrix, the sum of hub-FOB DVs for that hub in the hub-FOB matrix must also equal one. To ensure this, a linking constraint is necessary. A row along the bottom of the matrix sums up the hub-

FOB DVs for each hub. The linking constraint maintains that the difference between hub DV in the spoke-hub matrix and the sum of the hub-FOB DVs in the hub-FOB matrix must be equal to zero; or as formulated:

$$\left(\sum_{F=1}^{m} Y_{HF}\right) - \left(X_{HH}\right) = 0,$$

For all values of H (1 thru n)
Where n = number of home-station bases in the model,
m = number of FOBs in the model,
Y_{HF} = Hub-FOB DV,
X_{HH} = X_{SH} DVs where $S = H$ (i.e. a hub DV)

3.3.2 Distance Objective

With the model's core now defined, the distance objective is easy to calculate. Figure D.5 provides a screenshot of the Distance Calculation Tab. Using the distances from Table 3.1, each spoke-hub combination has a distance value of d_{SH}, where:

d_{SH} = distance (miles) between Spoke S and Hub H

By multiplying the binary X_{SH} DVs from the spoke-hub matrix with the respective d_{SH}, a summation of the results provides the distance total (DT) for the solution; or as formulated:

$$DT = \sum_{S=1}^{n} \sum_{H=1}^{n} (X_{SH} * d_{SH}),$$

Where DT = model's total distance calculation
n = number of home-station bases in the model,
X_{SH} = Spoke-Hub DV,
d_{SH} = distance between Spoke, S, and Hub, H

Next, a single dimensional value function (SDVF) transforms the distance into a value, which ultimately feeds into the optimization calculation. Determination of the SDVF equation came by solving for the minimum DT with the model under no additional constraints. This resulted in a DT of 5458 miles. Therefore, the DT that earns the

greatest value, or DT_{Best}, comes when DT equals 5458. The lowest valued DT, DT_{Worst}, comes from multiplying DT_{Best} by a factor of 4, resulting in 21832 miles. Having these values allows for the calculation of the distance objective value, V_{Dist}, using:

$$V_{Dist} = 1 - \left(\frac{DT - DT_{Best}}{DT_{Worst} - DT_{Best}} \right)$$

Where V_{Dist} = value earned for the Distance objective
DT = model total distance calculation,
DT_{Best} = DT where distance objective earns a value of 1,
DT_{Worst} = DT where distance objective earns a value of 0

This equation returns a value of one when DT equals DT_{Best}, and zero when DT equals DT_{Worst}. The SDVF between DT_{Best} and DT_{Worst} has a negative linear slope. Additionally, DT_{Worst} serves as the upper bound, or UB^D, for DT, while DT_{Best} is the lower bound, LB^D. These bounds result in two new constraints on DT, where:

$$DT \le UB^{Dist}$$

Where DT = model total distance calculation,
UB^{Dist} = upper bound of DT

$$DT \ge LB^{Dist}$$

Where DT = model total distance calculation,
LB^{Dist} = lower bound of DT

Figure 3.4 below provides an illustration of the V_{Dist} SDVF. The V_{Dist} calculated by the SDVF ultimately factors into the objective function, as is explained later in this chapter.

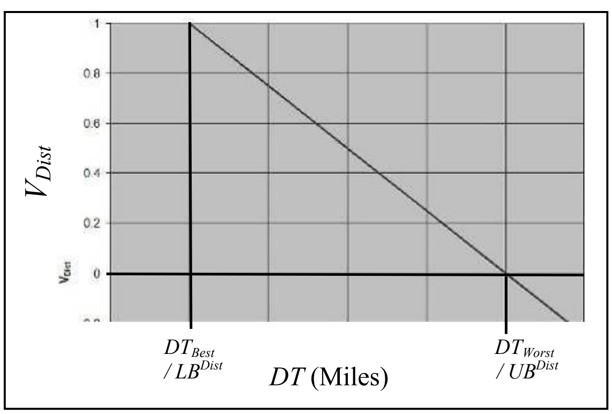


Figure 3.4 - SDVF for V_{Dist}

3.3.3 Manpower Objective

The manpower objective seeks to maximize the minimum overage of personnel at each FOB for each job specialty. An overage occurs when a network personnel total exceeds the demand at the FOB that the network supports, by career field. Figures D.6, D.7, and D.8 provide snapshots of the model's Manpower Calculation Tab. Table 3.3 provides the number of personnel, by career field, available at each Home-Station base; furthermore denoted as SS_{SC}, where:

SS_{SC} = number of personnel supplied from Spoke, *S,* in career field, *C*

By performing a sum product of SS_{SC} with the binary DVs of the Spoke-Hub matrix, for each hub and each career field, the model determines the hub supply, HS_{HC}, using:

$$HS_{HC} = \sum_{S=1}^{n} \left(SS_{SC} * X_{SH} \right) ,$$

For all values of *C* (1 thru *j*) and all values of *H* (1 thru *n*)
Where HS_{HC} = supply for cycle at Hub, *H*, in career field, *C,*
n = number of Home-Station bases in the model,
j = number of career fields in the model,
SS_{SC} = supply from Spoke, *S*, in career field, *C*,
X_{SH} = Spoke-Hub DV

Table 3.2 summarizes each FOBs per bucket personnel needs. The total demand is then calculated by multiplying the per bucket needs by the number of buckets; or $N_{Buckets}$. Section 2.5 states that four buckets are needed to minimize the change in loss of manpower. However, since this model's scope excludes key resources from Guard, Reserve, and OCONUS forces, this research assumes that these forces account for one bucket at each cluster. Therefore, $N_{Buckets}$ is equal to three, and the demand is as follows:

$FD_{FC} = N_{Buckets}\left(BD_{FC}\right)$, Where FD_{FC} = demand for cycle at FOB, *F*, in career field, *C,*
$N_{Buckets}$ = number of buckets per cycle,
BD_{FC} = demand per bucket at FOB, *F*, in career field *C*

Knowing the values for FD_{FC} allows for the calculation of the demand at each hub. Performing a sum-product of FD_{FC} with the binary DVs of the Hub-FOB matrix, for each hub and each career field, determines the Hub Demand, HD_{HC}; or as formulated:

$HD_{HC} = \sum_{F=1}^{m}\left(FD_{FC} * Y_{HF}\right)$, For all values of *C* (1 thru *j*) and all values of *H* (1 thru *n*)
Where HD_{HC} = demand for cycle at Hub, *H*, in career field, *C,*
m = number of FOBs in the model,
n = number of home station bases in the model,
j = number of career fields in the model,
FD_{FC} = demand for cycle at FOB, *F*, in career field, *C,*
Y_{HF} = Hub-FOB DV

With the supply and demand values known for each Hub, the next step is to determine the overages. In the overage calculation, a null factor masks bases that the model considers for, but does not use as, a Hub. To mask unused hubs, the null factor, NF_{MP}, must be a large negative number. An acceptable value for NF_{MP} is -99. With this, the overage calculation is as follows:

$$HO_{HC} = HS_{HC} - HD_{HC} + (X_{HH} - 1)NF_{MP}$$

Where HO_{HC} = cycle's overage at Hub, *H*, in career field, *C*
HS_{HC} = cycle's supply for a given *H* and *C,*
HD_{HC} = cycle's demand for a given *H* and *C,*
NF_{MP} = manpower null factor,
X_{HH} = X_{SH} DVs where $S = H$ (i.e. a hub DV)
For all values of *H* (1 thru *n*)

Using the Hub overages, a new DV, $Z^{MP}{}_{C}$, finds the smallest value of the Hub overages for each of the career fields. The following constraint bounds $Z^{MP}{}_{C}$:

$HO_{HC} \geq Z_{C}^{MP}$, For all Hubs, H, (1 thru n), and for all Career Fields, C, (1 thru j)
Where Z^{MP}_{C} = DV depicting smallest overage for the given C,
HO_{HC} = cycle's overage at Hub, H, in career field, C

To assist in determining the best values for Z^{MP}_{C}, additional constraints enforce an upper bound, UB^{MP}_{C}, and a lower bound, LB^{MP}_{C}, on the DVs for each career field. LB^{MP}_{C} is equal to zero for all career fields, while UB^{MP}_{C} is equal to the career field's rounded down, total overage averaged across the nine FOBs. The formulations for the upper and lower bound constraints are:

$Z_{C}^{MP} \leq UB_{C}^{MP}$, For all career fields, C, (1 thru j)
Where Z^{MP}_{C} = DV depicting smallest overage for the given C,
UB^{MP}_{C} = upper bound of the Z^{MP}_{C} DV

$Z_{C}^{MP} \geq LB_{C}^{MP}$, For all career fields, C , (1 thru j)
Where Z^{MP}_{C} = DV depicting smallest overage for the given C,
LB^{MP}_{C} = lower bound of the Z^{MP}_{C} DV

The value calculations for each career field vary due to differing best-case overage factors. The worst-case factor, $CO_{Worst,C}$ for each career field is set to zero. Determining the best-case factor, $CO_{Best,C}$ requires a number of calculations. First calculated is each career field's total overage using:

$$TO_{C} = \left(\sum_{S=1}^{n} SS_{SC} \right) - \left(\sum_{F=1}^{m} FD_{FC} \right)$$

For all career fields, C, (1 thru j)
Where TO_{C} = total cycle overage for a given C,
SS_{SC} = supply from Spoke, S, in career field, C,
FD_{FC} = demand for cycle at FOB, F, in career field, C,
n = number of home station bases in the model,
m = number of FOBs in the model

To maximize the minimum career field overage, the model divides TO_C by the number of FOBs. Next, due to the extremely low likelihood of achieving an evenly divided solution, the model reduces the averaged overage by multiplying it by a factor proportional to each career field's total supply and total demand. Finally, the model selects $CO_{Best,C}$ to be the lowest rounded value between this final calculation and the averaged overage found in step two. The complete calculation is as follows:

$$CO_{Best,C} = Min\left[Int\left[\frac{TO_C}{m} \times \frac{0.25\sum_{S=1}^{n} SS_{SC}}{\sum_{F=1}^{m} FD_{FC}} \right], Int\left[\frac{TO_C}{m} \right] \right]$$

For all career fields, C, (1 thru j)
Where $CO_{Best,C}$ = Best case overage
for a given C,
TO_C = total cycle overage for a given C,
m = number of FOB in the model,
n = number of home station bases,
SS_{SC} = supply from Spoke, S, for a given C,
FD_{FC} = demand at FOB, F, for a given C

The distance objective uses it own SDVF, shown in Figure 3.5, to calculate the value earned by each career field, CV_C. This calculation is as follows:

$$CV_C = 1 - \left(\frac{CO_{Best,C} - Z_C^{MP}}{CO_{Best,C} - CO_{Worst,C}} \right)$$

For all career fields, C, (1 thru j)
Where CV_C = earned value for a given C,
$CO_{Best,C}$ = Best case overage for a given C,
$CO_{Worst,C}$ = Worst case overage for a given C,
$Z^{MP}{}_C$ = DV depicting smallest overage for a given C

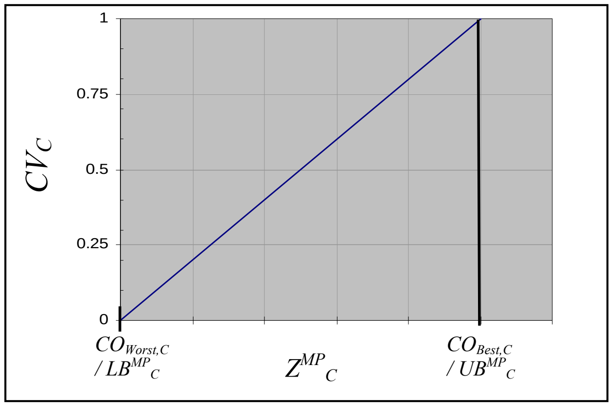


Figure 3.5 – SDVF for CV_C

Before calculating the total value earned in the Manpower objective, the model must consider the fact that each career field overage carries a different magnitude of importance, IC_C, based on the mission impact if not enough career field personnel are available. This magnitude of importance allows for the calculation of localized weighting. One method of determining weight involves ranking the objectives from least to most important, then assigning the least important objective with one unit of importance. Then, working from least to most important, each objective receives its own importance score by comparing it to objectives already scored. For example, if the second least important objective is twice as important as the first, then it receives a score of two. When all the scoring is complete, calculate an objective's weight by dividing its importance score by the sum of all the scores. The weights for all the objectives should then add to one. (Kirkwood, 1997:p70)

Following this method, personal experience and basic reasoning allowed for determining each career field's IC_C. Notable from these determinations is that the IC_C values for Superintendent, First Sergeant, and Supply are equal to zero. This is to

account for the facts that 1) insufficient data was available for these career fields, and 2) other career fields can fill Superintendent and First Sergeant requirements, and other squadrons can fill Supply personnel requirements. Another notable fact is that the Chief career field has an IC_C value of just one. This is primarily to help minimize loss in the value calculation because of the Chief career field's low total overage value. Table 3.4 summarizes the IC_C values.

Table 3.4 - Magnitudes of Importance for Career Fields

Career Field, C	Magnitude of Importance, IC_C
1-Officer	8
2-Chief	1
3-Superintendent	0
4-First Sergeant	0
5-Supply	0
6-Electrical	6
7-Power Pro	6
8-HVAC	6
9-Pavements	6
10-Structures	6
11-Utilities	6
12-Liquid Fuels	2
13-Pest Mgmt	2
14-Engineer Asst	8
15-Ops Mgmt	3

To find the Manpower objective's total value, V_{MP}, the model performs a sum-product of each CV_C and a factor proportional to the respective IC_C values using:

$$V_{MP} = \sum_{C=1}^{j} CV_C \left(\frac{IC_C}{\left[\sum_{C'=1}^{j} IC_{C'} \right]} \right)$$

Where V_{MP} = total value earned for the Manpower objective,
CV_C = earned value for a given career field, C,
IC_C = magnitude of importance for a given C,
j = number of career fields in the model

3.3.4 Mission Matching Objective

The Mission Matching objective calculation seeks to maximize the number of missions matched between FOBs and the bases that support them, for each of the seven defined missions. The objective earns value when a supporting base's mission matches a mission at the FOB. Figure D.11 provides a screenshot of the Mission Matching Calculation Tab from the model.

Table 3.2 defines the demand, using binary code to represent whether a mission does or does not exist at an FOB. The model defines this value as FM_{FM}, where:

$$FM_{FM} = \begin{cases} 1 & \text{If mission } M \text{ is conducted at FOB } F \\ 0 & \text{Otherwise} \end{cases}$$

Similarly, Table 3.3 defines the supply, using binary code to represent whether a mission does or does not exist at a home-station (Spoke) base. The model defines this Spoke mission value as SM_{SM}, where:

$$SM_{SM} = \begin{cases} 1 & \text{If mission } M \text{ is conducted at Spoke } S \\ 0 & \text{Otherwise} \end{cases}$$

To determine the overages, the model first calculates the mission supply, MS_{HM}, and mission demand, MD_{HM}, at the hubs using the Spoke-Hub and Hub-FOB binary DV matrices. The formulations for these calculations are as follows:

$$MS_{HM} = \sum_{S=1}^{n} \left(SM_{SM} * X_{SH} \right)$$

For all missions, M, (1 thru i) and all Hubs, H, (1 thru n)
Where i = number of missions in the model,
n = number of home station bases in the model,
MS_{HM} = mission supply for the given H and M,
SM_{HM} = mission demand for the given H and M,
X_{SH} = Spoke-Hub DV

$$MD_{HM} = \sum_{F=1}^{m} \left(FM_{FM} * Y_{HF} \right)$$

For all missions, M, (1 thru i) and all Hubs, H, (1 thru n)
Where i = number of missions in the model,
m = number of FOBs in the model,
MD_{HM} = mission demand for the given M and H,
FM_{FM} = mission demand for the given M, and FOB, F,
Y_{HF} = Hub-FOB DV

With these values known, the next step is to determine the mission overages, MO_{HM}. In the overage calculation, a null factor helps by masking bases considered for, but not used as, a Hub. This null factor, NF_{MM}, must be a large (with respect to the objective values) negative number. An acceptable value for NF_{MM} is -10. With this, the overage calculation is as follows:

$$MO_{HM} = MS_{HM} + (1 - MD_{HM})NF_{MM} + (X_{HH} - 1)NF_{MM}$$

For all Hubs, H (1 thru n)
Where MO_{HM} = mission, M, overage at a given H,
MS_{HM} = mission supply for the given H and M,
MD_{HM} = mission demand for the given H and M,
NF_{MM} = null factor for the Mission Matching objective,
X_{HH} = X_{SH} DVs where $S = H$ (i.e. a hub DV)

Using the Hub overages, a new Decision Variable, $Z^{MM}{}_{M}$, finds the smallest value of the Hub overages for each of the missions. The following constraint bounds $Z^{MM}{}_{M}$:

$MO_{HM} \geq Z_{M}^{MM}$ For all Hubs, H (1 thru n), and for all missions, M (1 thru i)
Where $Z^{MM}{}_{M}$ = DV depicting the lowest overage for a given M,
MO_{HM} = overage for a given M and H

Each mission's value calculation follows the same SDVF, as model testing shows that the optimal best case factors, $MO_{Best,M}$, and worst-case factors, $MO_{Worst,M}$, are one and zero, respectively. The upper bound, UB^{MM}_{M}, and lower bound, LB^{MM}_{M}, values are also equal to one and zero, respectively. These values result in the following constraint:

$$Z_M^{MM} \le UB_M^{MM}$$

For all missions, *M,* (1 thru *i*)
Where Z^{MM}_{M} = DV, smallest number of *M* missions matched,
UB^{MM}_{M} = upper bound of the Z^{MM}_{M} DV

$$Z_M^{MM} \ge LB_M^{MM}$$

For all missions, *M,* (1 thru *i*)
Where Z^{MM}_{M} = DV, smallest number of *M* missions matched,
LB^{MP}_{C} = lower bound of the Z^{MM}_{M} DV

Next, the model employs an SDVF, shown in Figure 3.6, to calculate the value earned by each mission, MV_M. This calculation is as follows:

$$MV_M = 1 - \left(\frac{MO_{Best,M} - Z_M^{MM}}{MO_{Best,M} - MO_{Worst,M}} \right)$$

For all missions, *M,* (1 thru *i*)
Where MV_M = earned value for a given *M,*
$MO_{Best,M}$ = Best case score for a given *M*,
$MO_{Worst,M}$ = Worst case score for a given *M*,
Z^{MM}_{M} = DV depicting smallest score for a given *M*

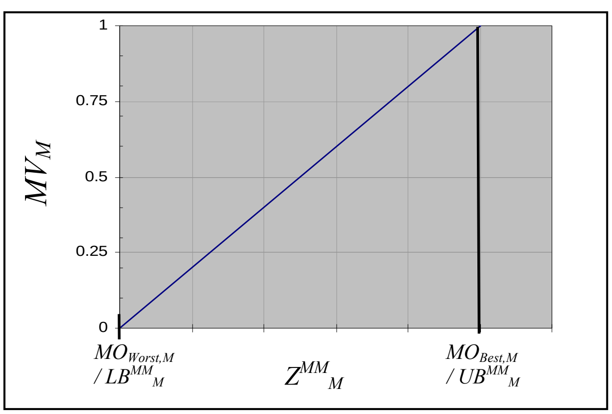


Figure 3.6 – SDVF for MV_M

Before calculating the total value earned in the Mission Matching objective, the model must consider the fact that each mission could carry a different magnitude of importance, IM_M. However, by setting all the IM_M values to one, all missions are given the same level of importance, thus simplifying the preliminary model, while still maintaining the capability to do future sensitivity analysis. Therefore:

$IM_M = 1$, for all missions, M (1 thru i)

To find the Mission Matching objective's total value, V_{MM}, the model performs a sum-product of each MV_M and a factor proportional to the respective IM_M values using:

$$V_{MM} = \sum_{M=1}^{i} MV_M \left(\frac{IM_M}{\left\lceil \sum_{M'=1}^{i} IM_{M'} \right\rceil} \right)$$

Where V_{MM} = total value earned for the Mission Match objective
i = number of missions in the model,
MV_M = earned value for a given mission, M,
IM_M = magnitude of importance for a given M
For all missions M, (1 thru i)

3.3.5 Airlift Objective

The Airlift objective seeks to maximize the minimum airlift capability over all the Hubs. Hubs gain one unit of airlift capability for each assigned Spoke base that has airlift capability. Figure D.9 provides a screen shot of the model's Airlift Calculation Tab. Table 3.3 summarizes Spoke airlift capability, denoted as SA_S, where:

$$SA_S = \begin{cases} 1 & \text{If Spoke } S \text{ has airlift capability} \\ 0 & \text{Otherwise} \end{cases}$$

Using this information, the model is able to determine Hub airlift capability, HA_H, by performing a sum-product of the Spoke-Hub DVs and the respective SA_S values. The formulation for this is as follows:

$$HA_H = \sum_{S=1}^{n} \left(SA_S * X_{SH} \right)$$

For all Hubs, H, (1 thru n)
Where n = number of home station bases in the model,
HA_H = total airlift capability at a given H,
SA_S = airlift capability at a given Spoke, S,
X_{SH} = Spoke-Hub DV

Next, for the Airlift objective calculation, the model masks all non-Hub bases with a null factor. The null factor for the Airlift objective, NF_{AC}, is set to -3, as there are only 19 airlift capable bases, which, when averaged over the 9 FOBs, results in a value no greater than 2. With this, the model finds Hub Airlift objective scores, AO_H, using:

$$AO_H = HA_H + (X_{HH} - 1)NF_{AC}$$

For all Hubs, H, (1 thru n)
Where AO_H = Airlift objective score at a given H,
HA_H = total airlift capability at a given H,
X_{HH} = X_{SH} DVs where $S = H$ (i.e. a hub DV),
NF_{AC} = null factor for the Airlift objective

Using the AO_H values, a new Decision Variable, Z^{AC}, finds the smallest value of the Hub Airlift objective scores. The following constraint bounds Z^{AC}:

$$AO_H \geq Z^{AC}$$

For all Hubs, H, (1 thru n)
Where Z^{AC} = DV depicting the lowest Airlift objective score,
AO_H = Airlift objective score at a given H

The value calculation uses another SDVF, shown in Figure 3.7, therefore the model needs a best-case factor, AO_{Best}, and a worst-case factor, AO_{Worst}. Following the same logic used to establish the NF_{AC} value, the best-case value is set equal to two. The

worst-case value is set to zero. Similarly, the upper bound, UB^{AC}, is set to two, and the lower bound, LB^{AC}, is set to zero, resulting in the following constraints:

$$Z^{AC} \leq UB^{AC}$$

Where Z^{AC} = DV depicting the minimum airlift capability,
UB^{AC} = upper bound of the Z^{AC} DV

$$Z^{AC} \geq LB^{AC}$$

Where Z^{AC} = DV depicting the minimum airlift capability,
LB^{AC} = lower bound of the Z^{AC} DV

Now the SDVF can determine the Airlift objectives value, V_{AC}, using:

$$V_{AC} = 1 - \left(\frac{AO_{Best} - Z^{AC}}{AO_{Best} - AO_{Worst}} \right)$$

Where V_{AC} = earned value for the Airlift objective
AO_{Best} = Best case score for the Airlift objective,
AO_{Worst} = Worst case score for the Airlift objective,
Z^{AC} = DV depicting lowest Airlift objective score

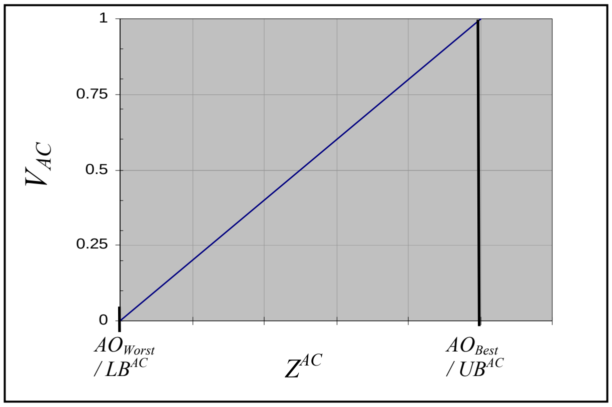


Figure 3.7 – SDVF for V_{AC}

3.3.6 Weather Objective

The Weather objective seeks to maximize the number of cold-weather bases assigned to the model's only cold-weather FOB, Manas AB. Figure D.10 shows a screenshot of the Weather Calculation Tab. Table 3.3 denotes base cold weather status using binary variables SW_S, where:

$$SW_S = \begin{cases} 1 & \text{If Spoke } S \text{ is a cold-weather base} \\ 0 & \text{Otherwise} \end{cases}$$

Using this information, the model is able to determine the number of cold-weather bases at each of the Hubs, HW_H, by performing a sum-product of the Spoke-Hub DVs and the respective SW_S values. The formulation for this is as follows:

$$HW_H = \sum_{S=1}^{n} \left(SW_S * X_{SH} \right)$$ For all Hubs, *H,* (1 thru *n*)
Where *n* = number of home station bases in the model,
HW_H = number of cold weather bases assigned to a given *H*,
SW_S = binary cold weather value for a given Spoke, *S*,
X_{SH} = Spoke-Hub DV

The model must also mask all potential Hubs that are not supporting Manas AB, regardless of whether or not they are an actual Hub. To do this, it uses a null factor, NF_{WX}, which has an acceptable value of -4. The model can now calculate each Hub's cold weather score, WO_H, keeping in mind that Manas AB is currently the only FOB of concern, though the model could consider more. Given this, the model only considers the single FOB (i.e. *m* = 8), and the Hub cold weather score calculation is as follows:

$$WO_H = HW_H + (X_{HH} - 1)NF_{WX}$$ For all Hubs, *H,* (1 thru *n*)
Where WO_H = Weather objective score at a given *H,*
HW_H = Number of cold weather bases at a given *H,*
NF_{WX} = null factor for the Weather objective,
X_{HH} = X_{SH} DVs where *S* = *H* (i.e. a hub DV)

Using the WO_H values, a new Decision Variable, Z^{WX}, finds the smallest value of the Hub Weather objective scores, which should occur at the Manas AB Hub. The following constraint determines Z^{WX}:

$$WO_H \geq Z^{WX}$$ For all Hubs, *H,* (1 thru *n*)
Where Z^{WX} = DV depicting lowest Weather objective score,
WO_H = Weather objective score for a given H

The value calculation uses another SDVF, shown in Figure 3.8; therefore, the model needs a best-case factor, WO_{Best}, and a worst-case factor, WO_{Worst}. After much trial and error analysis, best-case value is set to three. The worst-case value is set to zero; that is, when the model assigns no cold weather bases to Manas AB, the objective earns zero value. Similarly, the upper bound, UB^{WX}, is set to three, and the lower bound, LB^{WX}, is set to zero, resulting in the following constraints:

$Z^{WX} \le UB^{WX}$ Where Z^{WX} = DV depicting the lowest Weather objective score, UB^{WX} = upper bound of the Z^{WX} DV

$Z^{WX} \ge LB^{WX}$ Where Z^{WX} = DV depicting the lowest Weather objective score, LB^{WX} = lower bound of the Z^{WX} DV

Now the SDVF can determine the Weather objectives value, V_{WX}, using:

$$V_{WX} = 1 - \left(\frac{WO_{Best} - Z^{WX}}{WO_{Best} - WO_{Worst}} \right)$$

Where V_{WX} = value earned for the Weather objective
WO_{Best} = best case score for the weather objective,
WO_{Worst} = worst case score for the Weather objective,
Z^{WX} = DV depicting lowest Weather objective score

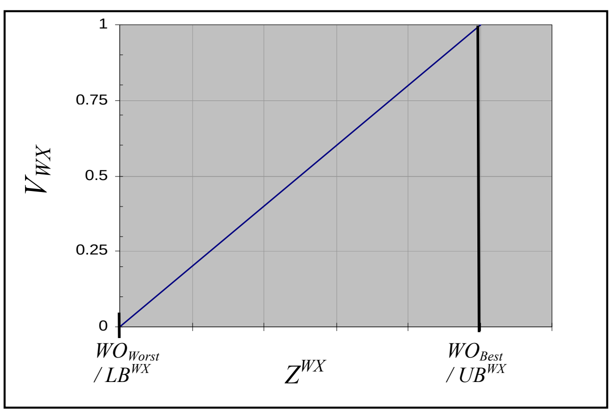


Figure 3.8 – SDVF for V_{WX}

3.4 Determining Weights

Whenever dealing with multiple, and often conflicting, objectives, weights for terms in the objective function become a major factor in determining best solution. In this model, there are five objectives, thereby requiring five corresponding weights. Using the same logic applied in Section 3.3.3 for determining magnitudes of importance, the first step in determining weights is to rank order the objectives by importance, from least to greatest. Relying on personal experience, the order of objectives from least to most important is: 1) Mission Matching, 2) Weather, 3) Airlift, 4) Manpower, and 5) Distance.

The second step to weighting is to determine, by what magnitude, the non-least important objectives compare to the least important objective. A comparison of actual and expected results shows that the Mission Matching, Airlift, and Weather objectives are equally least important objectives. By assigning a weight of one, the model essentially treats these objectives as having minimum value. The balance between the Manpower and Distance objectives seems less clear. While maximizing the manpower overage appears most important, doing so means sacrificing distance, which leads to non-regionalized hub-and-spoke clusters. In addition, this research already assumes that manpower shortfalls are accounted for by organizations outside of the model's scope, to include Guard, Reserve, PACAF, and USAFE forces. Analysis of the actual and expected results shows that the Manpower objective is twice as important, and the Distance objective is ten times as important, as any one of the least important objectives.

The final step in weighting is to sum up the magnitudes of importance and apply a factor to each of the objectives based on these values. Table 3.5 shows the final weights for the five objectives.

3.5 The Objective Function

Having the values and weights for each of the objectives now allows formulation of the model's objective function (*OF*), which is a sum product of the values with their respective weights:

$$\text{Maximize: } OF = (V_{MM}W_{MM}) + (V_{WX}W_{WX}) + (V_{AC}W_{AC}) + (V_{Dist}W_{Dist}) + (V_{MP}W_{MP})$$

Where V_{MM} = value earned for the Mission Matching objective,
W_{MM} = weighting for the Mission Matching objective,
V_{WX} = value earned for the Weather objective,
W_{WX} = weighting for the Weather objective,
V_{AC} = value earned for the Airlift objective,
W_{AC} = weighting for the Airlift objective,
V_{Dist} = value earned for the Distance objective,
W_{Dist} = weighting for the Distance objective,
V_{MP} = value earned for the Manpower objective,
W_{MP} = weighting for the Manpower objective

Table 3.5 and Figure D.4 show a screenshot of the model's Objective Function Calculation Tab. Figure D.3 shows a screenshot of the lower half of the Optimization Tab, which demonstrates how the model calculates each of the objective's scores. In table 3.5, the objective score is dependent on each objective's formulation. For the Manpower and Mission Matching objectives, the score is the summed locally weighted values across all Career Fields and Missions, respectively. For the Distance objective, the score reflects the *DT* value. While for the Airlift and Weather objectives, the scores are the Z^{AC} and Z^{WX} values, respectively. The objective value is found by using each

objective's respective SDVF. An objective's weight is determined by dividing its magnitude of importance by the sum of all the magnitude of importance values. Finally, the weighted value is a multiplication of the objective values and the weights.

Table 3.5 - Objective Function Tab

	A	B	C	D	E	F
1	Objective	Objective Score	Objective Value	Magnitude of Importance	Weight of Objective	Weighted Value
2	Manning	0.743265	0.743265	2	0.1333333	0.099
3	Distance	8886	0.791	10	0.6666667	0.527
4	Airlift	1	0.5	1	0.0666667	0.033
5	Weather	3	1	1	0.0666667	0.067
6	Mission	0.571429	0.571429	1	0.0666667	0.038
7	TOTALS	NA	NA	15	1	0.7643

3.6 Summary

Chapter 3 presented and explained the methodology used in developing the LP model. First, it explains the models development by explaining how Hub-and-Spoke networking is applicable to the problem. The chapter provides a basic model to help identify the many nodes and arcs in the network. Next, there was a general overview of the model's DVs, objectives, and constraints, which provides the framework for the actual formulation. The construction of the model takes up the bulk of the chapter, providing a detailed breakdown of all the model's variables, parameters, and formulas that determine the value earned by each objective. Finally, combining the objective values with objective weighting results in the formulation of the objective function. Now, with the model built, Chapter 4 examines the results and looks at how sensitive the model is to adjustable parameters such as weights, magnitudes of importance, upper and lower bounds, and null factors.

4. ANALYSIS AND RESULTS

4.1 Chapter Overview

Chapter 4 looks at the model's results to determine whether it is functioning as expected, whether the solutions are reasonable given the assumptions, and how the model might be improved. The Scenario Evaluation section reviews a collection of solutions generated by the model. For each scenario, Appendix C includes a graphical depiction and solution summary, while the text provides a dictated investigation. Next, sensitivity analysis explores how the variation of model parameters, such as weights and bounds, affect the solution. Chapter 4 concludes with a discussion of overall findings.

4.2 Scenario Evaluations

By varying model parameters, such as weights and bounds, the solver engine was able to produce a number of hub-spoke network solutions, which met the current model's constraints. For each of the parameter change iterations, a single model could produce multiple solutions, or *scenarios,* depending on the run time allowed. These scenarios provide insight on how to calibrate the model to achieve reasonable results. In all, the evaluation process generated approximately 40 scenarios of varying degrees of attractiveness and acceptability. This research defines the ideal scenario as having high values in each of the objectives, meeting all constraints, and producing networks that have tight clustering. This section analyzes ten of these, each chosen based on when during the evaluation period the scenario's generation occurred, the test model's focus, and the values of the individual objectives and the objective function value. Figure 4.1 provides an overall summary of these ten scenarios.

Scenerio	Test Model	V_{Dist}	V_{MP}	V_{AC}	V_{WX}	V_{MM}	OF Value
10	N1	0.79064	0.74326	0.5	1	0.57143	0.76429
9	N2	0.77171	0.75603	0.5	1	0.71429	0.76290
8	M4	0.75205	0.89876	0.5	1	0.14286	0.73072
7	M2	0.76408	0.56930	0.5	1	0.57143	0.72339
6	B4	0.78930	0.47262	0.5	1	0.14286	0.69874
5	B6	0.80035	0.39020	0.5	1	0.14286	0.69512
4	E1	0.68981	0.60461	0.5	1	0.71429	0.68811
3	B5	0.75840	0.41847	0.5	1	0.28571	0.68044
2	C1	0.19177	0.53907	0.5	0.67	0.42857	0.30607
1	C5	0.04916	0.93255	0.5	0.67	0.28571	0.25394

Figure 4.1 – Summary of the Analysis Scenarios

Scenario 1: Objective function value = 0.25394 (Test Model C5)

Early development of the model placed greater emphasis on maximizing the Manpower objective. While this seems logical, under these conditions the model produces scenarios lacking balance between all objectives, particularly Distance. Figure C.1 shows that Scenario 1 has no clear boundaries between the nine networks. The distance total for this scenario is 21,027 miles, with a maximum arc distance of 2,893 miles. Scenario 1 does meet both the Airlift and Cold Weather objectives, as every network has at least one airlift asset, and Manas has support from two cold weather bases. For the Mission Matching objective, experienced personnel are available for eight of the 17 missions. Scenario 1 earns most its value from the Manpower objective, as key career fields earn very high minimum scores. Table C.1 provides a summary of Scenario 1, which, though feasible, scores as marginal overall due to its lack of clustering.

Scenario 2: Objective function value = 0.30607 (Test Model C1)

This alternative is a result of trying to balance the Distance and Manpower objectives. In a side-by-side comparison of Figures C.1 and C.2, Scenario 2 results

clearly improve on clustering. Table C.2 shows that the value gained by decreasing the distance total to 18,692 miles and maximum distance to 2,834 miles came as a trade-off in Manpower. While each career field does have a non-negative minimum value, and key career fields retained reasonably high values, Scenario 2 is not as strong as Scenario 1 in the Manpower objective. Scenario 2 does meet both Airlift and Cold Weather objectives, with a minimum Airlift score of one, and two cold weather bases supporting Manas. In the Mission Matching objective, experienced personnel are available for nine out of 17 missions. Overall, Scenario 2 is better than Scenario 1, having an acceptable trade-off between Distance and Manpower; however, there is still no clustering.

Scenario 3: Objective function value = 0.68044 (Test Model B5)

Scenario 3 appears to be closer to the desired balance in objectives, as seen in Figure C.3 and Table C.3. With a total distance of 9,414 miles and a maximum distance of 518, this alternative improves on total distance and has significantly tighter clusters. The Airlift objective score is unchanged, with a minimum airlift score of one. However, the Cold Weather objective is an improvement over the first two scenarios, with three cold weather bases now supporting Manas. The Mission Matching objective scores well, with experienced personnel supporting 12 of the 17 missions. However, the total value earned for the Manpower is lower than both Scenarios 1 and 2. Overall, the tight clustering of the networks, and the high marks earned in the Mission Matching, Cold Weather, and Airlift objectives, makes Scenario 3 a reasonable solution. While the Manpower objective score is less than desirable, there is a potential to overcome this by the addition of resources outside the model (Guard, Reserve, USAFE, and PACAF).

Scenario 4: Objective function value = 0.68811 (Test Model E1)

In the next iteration of development, Scenario 4 attempts to place significantly more weight on the distance objective, which results in a new set of clusters. As seen in Figure C.4 and Table C.4, the total distance remains low, at 10,537 miles, with a maximum distance of 994 miles. Manpower scores are slightly better than that seen in the previous two scenarios, and there is no change in the Airlift or Cold Weather objectives, when compared to Scenario 3. Under the Mission Matching objective, this scenario supports 13 of the 17 missions. However, though this scenario does yield high scores in nearly all objectives, it is still not perfect. Spokes such as McConnell AFB must travel too far, and there is a poorly defined boundary between the Sheppard AFB and Dyess AFB networks. Both of these issues stem from the Distance objective.

Scenario 5: Objective function value = 0.69512 (Test Model B6)

The generation of Scenario 5, shown in Figure C.5 and Table C.5, came from an earlier test model that places almost all emphasis on distance, and demonstrates where the balance between the objectives shifts too far. This alternative has the best total distance over all the scenarios, with only 8,727 total miles and a reasonable maximum distance of 796 miles. Again, the Airlift and Cold Weather objective values remain unchanged. In the Mission Matching objective, there are experienced personnel for nine of the 17 missions, which notably ties for the lowest score across the ten scenarios. Additionally, though all career fields do score non-negative minimum values, the total Manpower objective value is the lowest among all the scenarios, likely due to the low scores for key career fields. That said, this scenario's clustering is the best seen yet, with only one

minor concern for the distance between Beale AFB and its hub. Overall, Scenario 5 is worthy of further consideration given the potential to improve Manpower with resources outside the model, such as personnel from Guard, Reserve, or OCONUS.

Scenario 6: Objective function value = 0.69874 (Test Model B4)

Shown in Figure C.6 and Table C.6, Scenario 6 is similar to the previous scenario in that it shares the same Airlift, Cold Weather, and Mission Matching objective values. It differs in that it loses value from the Distance objective, due to an increase of less than 200 miles, to 8,909 total miles, and a maximum distance of 614 miles. In return for this tradeoff, the Manpower objective increases significantly, meaning this solution is closer to balancing the objectives. Overall, Scenario 6 has excellent clustering due to the Distance objective, and the Airlift, Cold Weather, and Manpower objectives all score within a reasonable range. However, the low score for the Mission Matching objective leaves Scenario 6 with some room for improvement.

Scenario 7: Objective function value = 0.72339 (Test Model M2)

With respect to the previous scenario, Scenario 7, shown in Figure C.7 and Table C.7, scores the same for the Airlift and Cold Weather objectives, improves in Mission Matching and Manpower objectives, and loses value in the Distance objective. Mission Matching improves significantly, with support for 10 out of 17 missions. The Manpower objective improves by yielding reasonable levels of overages in key career fields. However, the minor drop in the Distance objective's score is a significant one. The addition 400 miles, bringing the total to 9,321 miles, and the maximum distance to 796

miles, results in undesirable clustering; specifically, there are poorly defined boundaries between the Cannon AFB and Dyess AFB networks, as well as between the Bolling AFB and Dover AFB clusters. For this reason, Scenario 7 is likely not the best alternative.

Scenario 8: Objective function value = 0.73072 (Test Model M4)

Scenario 8, shown in Figure C.8 and Table C.8, is second out of all scenarios in the Manpower objective; only Scenario 1 is better. This high score is due to the outstanding overages in key Career Fields, which had minimum overages such as 15 Officers, 27 Electricians, 41 HVAC, 42 Structures, 41 Utilities, and 25 EAs. In comparison with Scenario 7, the Distance objective value only decreases slightly, with a total of 9,518 miles and a maximum of 1,014 miles. These values produce good clusters in this scenario. There was no change in the Airlift objective, with a minimum of one Airlift capability at each Hub. The Cold Weather objective still earns full value, as in the previous scenarios; however, this scenario actually has four cold weather bases at Manas. On the downside, Scenario 8's Mission Matching score ties for lowest among all scenarios. As a result, Scenario 8 is an acceptable solution with room for improvement.

Scenario 9: Objective function value = 0.76290 (Test Model N2)

Scenario 9, shown in Figure C.9 and Table C.9, is a result of the most recent, analysis driven, updates to the model. Using clearly defined upper and lower bounds, as Chapter 3 explains, the model produced solutions closer to the desired results. Scenario 9 yields some of the highest values across all objectives. The Distance objective score is fourth best overall, with a total distance of 9,196 miles, and a maximum distance of 710

miles. The Manpower objective is third best overall, mostly due to the relatively high minimum overage scores in key career fields. The Mission Matching objective ties for best overall, with the scenario supporting 13 out of 17 missions. There were no value changes for the two remaining objectives. Overall, Scenario 9 shows good clustering, and is defiantly worth consideration.

Scenario 10: Objective function value = 0.76429 (Test Model N1)

The best model generated scenario, both in value and in regional clustering, is Scenario 10; shown in Figure C.10 and Table C.10. Again, this scenario is the result of the latest improvements in the model, and yields some of the highest marks across all objectives. The Distance objective score is second overall, with a total distance of 8,886 miles, and a maximum distance of 757 miles. The Manpower objective scores fourth overall, again due to relatively high minimum overage scores in key career fields. The Mission Matching objective ties for third overall, with the scenario supporting 12 out of 17 missions. Again, there are no changes in the Airlift or Cold Weather objectives. Overall, Scenario 10 shows some the best clusters, with well-defined network regions, and yields great scores across all objectives. For these reasons, Scenario 10 is the most idealistic alternative among the all scenarios generated by the model.

4.3 Sensitivity Analysis

The model uses a number of parameters that create fluctuations in the solution. The most significant of these parameters are objective weights and bounds. This section covers both single and two-way sensitivity analysis of some of these parameters, using

the above scenarios as points of reference. The analysis also uses the model's *OF* formula, as seen in Section 3.5, along with the initial values shown in Table 3.5, and the individual objective values as shown in Figure 4.1.

4.3.1 Single Factor Analysis of W_{Dist}

For the Distance objective, the model's default weight is set at 10. Therefore, the sensitivity analysis explores the resulting Objective Function value with W_{Dist} varying from zero to 20, with all other values held constant. The results, shown in Figure 4.2, illustrate that while Scenario 10 earns the best *OF* value for the current weight or better, for any lower W_{Dist} Scenario 9 earns a higher *OF* value. Furthermore, Scenario 9 scores relatively equal to Scenario 10 when W_{Dist} has a value of 10 or greater. This analysis identifies a significant concern over the proper weighting of W_{Dist}.

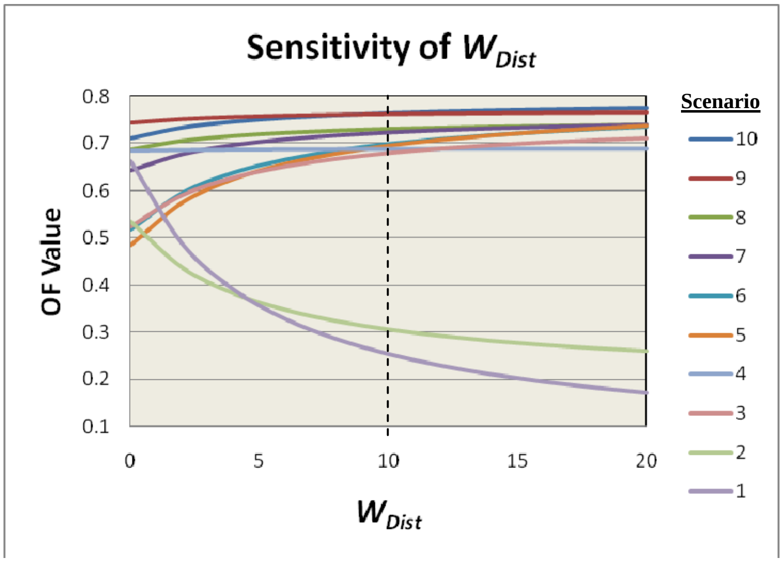


Figure 4.2 - Sensitivity Analysis for W_{Dist}

4.3.2 Single Factor Analysis of W_{MP}

The Manpower objective's weight has a default value of two. Since weights must be non-negative, this analysis investigates the variance of W_{MP} over a range of zero to 10, with all other values held constant. Figure 4.3 shows the results of this analysis. Across the entire range of the analysis, Scenario's 9 and 10 appear to tie in *OF* value. Furthermore, both of these scenarios have the highest *OF* value when W_{MP} has a value of plus or minus two from the current value. However, once W_{MP} attains a weight of five or more, Scenario 8 achieves the best *OF* value. These results show that there is a minor concern over the proper weighting of W_{MP}.

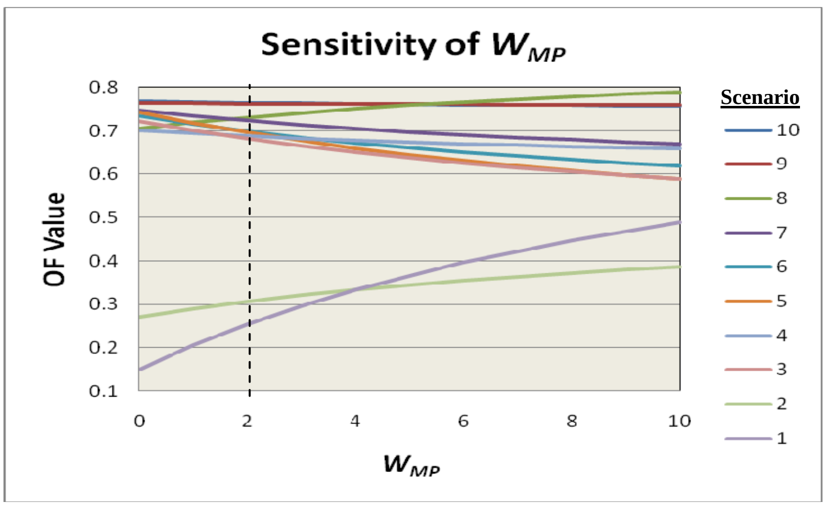


Figure 4.3 - Sensitivity Analysis for W_{MP}

4.3.3 Single Factor Analysis of W_{AC}

The Airlift objective's weight has a default value of one. This analysis investigates the variance of W_{AC} over a range of zero to 10, with all other values held constant. Figure 4.4 shows the results of this analysis. Given that this is a reasonable range, the analysis shows that W_{AC} in this range does not affect solution quality.

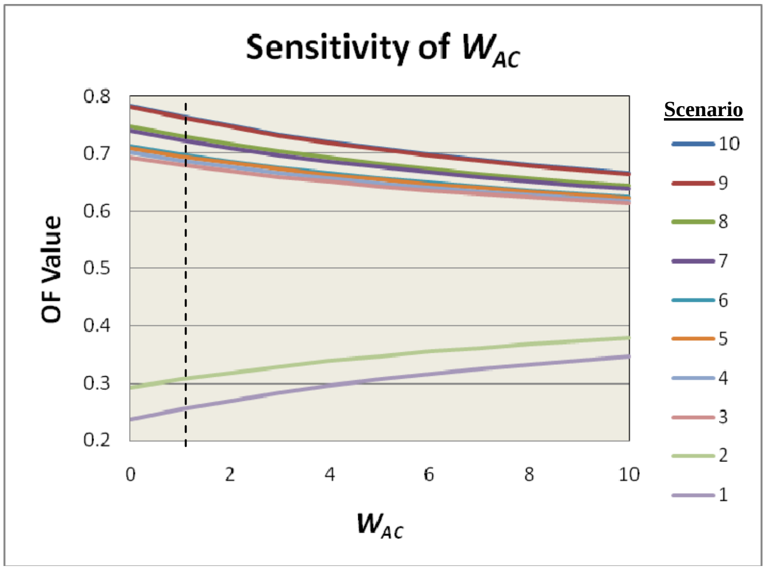


Figure 4.4 – Sensitivity Analysis of W_{AC}

4.3.4 Single Factor Analysis of W_{WX}

The Cold Weather objective's weight has a default value of one. This analysis investigates the variance of W_{WX} over a range of zero to 10, with all other values held constant. Figure 4.5 shows the results of this analysis. Given that this is a reasonable range, the analysis shows that W_{WX} in this range does not affect solution quality.

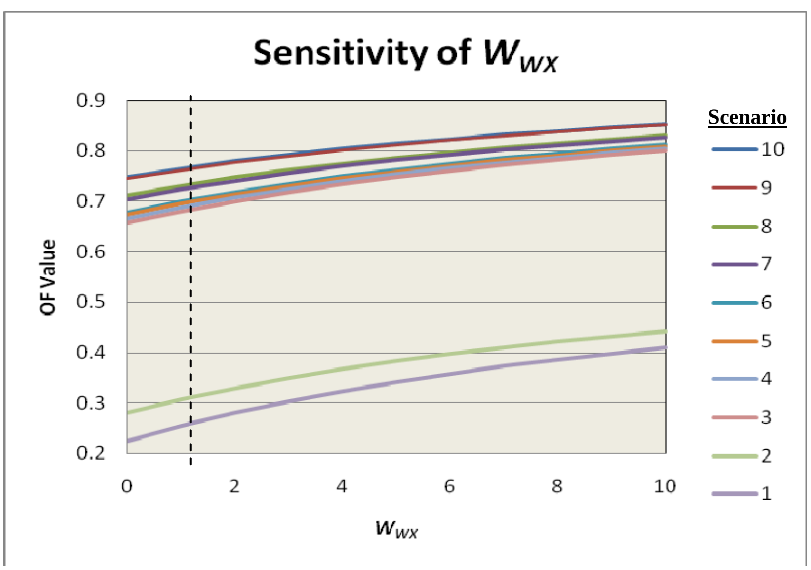


Figure 4.5 – Sensitivity Analysis of W_{WX}

4.3.5 Single Factor Analysis of W_{MM}

The Mission Matching objective's weight has a default value of one. This analysis investigates the variance of W_{MM} over a range of zero to 10, with all other values held constant. Figure 4.6 shows the results of this analysis. The results identify a high level of concern over the proper weighting of W_{MM} as they show Scenario 9 achieveing the best *OF* value for all values greater than the current value of one. Furthermore, when W_{MM} drops to zero, Scenarios 10 and 8 have approximately equal *OF* values. To properly investigate this concern, the next logical step is to perform two-way sensitivity analysis to see how changing multiple parameters affects the solution.

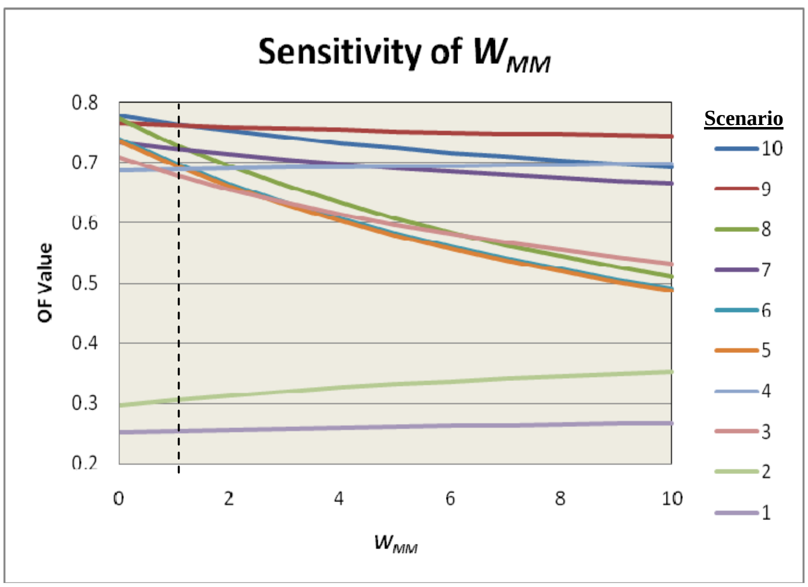


Figure 4.6 – Sensitivity Analysis of W_{MM}

4.3.6 Two-Way Analysis of W_{Dist} and W_{MP}

The two-way analysis uses a similar approach to that seen in the single factor analysis, only that it adjusts two factors, and it reports only the best solution for the given values. By performing this analysis on all ten possible combinations of the five weight

factors, this research identifies four notable sensitivity trends. The first trend comes from the analysis of W_{Dist} and W_{MP}, which have default values of 10 and 2 respectively. Shown in Figure 4.7, this pair is the most dynamic of all 10 two-way analysis combinations. The analysis shows that Scenario 10 has the highest *OF* value as long as the ratio of W_{Dist} to W_{MP} remains at or above the current level. If the ratio drops, Scenarios 8 and 9 become best, dependent on W_{MP}. The analysis also shows instances where Scenarios 1 and 4 have the best *OF* value; however, this only happens when W_{Dist} equals zero, which is an unlikely occurrence, and therefore should not be of concern.

	W_{Dist}										
W_{MP}	0	2	4	6	8	10	12	14	16	18	20
0	4	9	9	9	10	10	10	10	10	10	10
1	9	9	9	9	9	10	10	10	10	10	10
2	9	9	9	9	9	10	10	10	10	10	10
3	9	9	9	9	9	10	10	10	10	10	10
4	9	9	9	9	9	9	10	10	10	10	10
5	8	8	8	8	9	9	10	10	10	10	10
6	1	8	8	8	8	8	8	10	10	10	10
7	1	8	8	8	8	8	8	8	8	10	10
8	1	8	8	8	8	8	8	8	8	8	8
9	1	8	8	8	8	8	8	8	8	8	8
10	1	8	8	8	8	8	8	8	8	8	8

Figure 4.7 – Two-Way Analysis of W_{Dist} and W_{MP}

4.3.7 Two-Way Analysis of W_{Dist} and W_{MM}

The next trend comes from the analysis of W_{Dist} and W_{MM}, which have default values of 10 and 1 respectively. The analysis, shown in Figure 4.8, again identifies how sensitive the objective function is to these two weights. It essentially shows that Scenario 10 only has the best *OF* value if W_{Dis} is 10 or greater, and, in all but two instances, where W_{MM} is one or less. Scenario 8 has the best *OF* value when WMM is equal to zero and WDist is less than 10. However, this research views this as an unlikely situation. For all

other values of W_{Dist} and W_{MM}, Scenario 9 comes out as having the best *OF* value. This trend illustrates the fact that Scenario 9 is a competitive alternative to Scenario 10.

	W_{Dist}										
W_{MM}	0	2	4	6	8	10	12	14	16	18	20
0	8	8	8	8	8	10	10	10	10	10	10
1	9	9	9	9	9	10	10	10	10	10	10
2	9	9	9	9	9	9	9	9	9	10	10
3	9	9	9	9	9	9	9	9	9	9	9
4	9	9	9	9	9	9	9	9	9	9	9
5	9	9	9	9	9	9	9	9	9	9	9
6	9	9	9	9	9	9	9	9	9	9	9
7	9	9	9	9	9	9	9	9	9	9	9
8	9	9	9	9	9	9	9	9	9	9	9
9	9	9	9	9	9	9	9	9	9	9	9
10	9	9	9	9	9	9	9	9	9	9	9

Figure 4.8 – Two-Way Analysis of W_{Dist} and W_{MM}

4.3.8 Two-Way Analysis of W_{MP} and W_{MM}

The third trend comes from the analysis of W_{MP} and W_{MM}, which have default values of two and one, respectively. The analysis, shown in Figure 4.9, reveals that Scenario 10 is only has the best *OF* value in six instances on this analysis. Considering the fact that it is unlikely for either W_{MP} or W_{MM} to equal zero, the number of instances where Scenario 10 has the best *OF* value drops to three. This occurs only when W_{MM} equals one and when W_{MP} is three or less. For all but six other instances, the best solution is Scenario 9. Scenario 8 has the best *OF* value when W_{MM} is one or less and W_{MP} is six or more. These results again show that Scenario 9 is a competitive alternative.

	W_{MP}										
W_{MM}	0	1	2	3	4	5	6	7	8	9	10
0	5	10	10	8	8	8	8	8	8	8	8
1	10	10	10	10	9	9	8	8	8	8	8
2	9	9	9	9	9	9	9	9	9	9	8
3	9	9	9	9	9	9	9	9	9	9	9
4	9	9	9	9	9	9	9	9	9	9	9
5	9	9	9	9	9	9	9	9	9	9	9
6	9	9	9	9	9	9	9	9	9	9	9
7	9	9	9	9	9	9	9	9	9	9	9
8	9	9	9	9	9	9	9	9	9	9	9
9	9	9	9	9	9	9	9	9	9	9	9
10	9	9	9	9	9	9	9	9	9	9	9

Figure 4.9 – Two-Way Analysis of W_{MP} and W_{MM}

4.3.9 Two-Way Analysis of W_{Dist}, W_{MP}, or W_{MM} with either W_{AC} or W_{WX}

This final trend shows that the values of W_{AC} or W_{WX} have no effect in determining the best *OF* value, and is actually visible in six of the ten possible two-way sensitivity analysis combinations. Figure 4.10 shows the two-way analysis for W_{Dist} with either W_{AC} or W_{WX}. These results both show that Scenario 10 has the best *OF* value for any value of W_{Dist} of 10 or more, regardless of the value of W_{AC} or W_{WX}. For any value of W_{Dist} less than 10, Scenario 9 has a better *OF* value; this trend matches that seen in the single-factor analysis of W_{Dist}. Figure 4.11 shows the two-way analysis for W_{MP} with either W_{AC} or W_{WX}. These results both show that Scenario 10 has a better *OF* value for any W_{MP} value of four or less, regardless of the value of W_{AC} or W_{WX}. For any value of W_{MP} greater than four, Scenarios 8 and 9 are better; this trend matches that seen in the single-factor analysis of W_{MP}. Figure 4.12 shows the two-way analysis for W_{MM} with either W_{AC} or W_{WX}. These results both show that Scenario 10 has the best *OF* value for any value of W_{MM} of one or less, regardless of the value of W_{AC} or W_{WX}. For any value of W_{MM} greater than one, Scenario 9 is better; this trend matches that seen in the single-factor analysis of W_{MM}. Together, these six observations show that while the optimal solution is sensitive to the value of W_{Dist}, W_{MP}, or W_{MM}, it is not sensitive to W_{AC} or W_{WX}, as is noted in the single factor analysis. It is also note worthy that in the one two-way analysis combination not shown in this report, W_{AC} with W_{WX}, Scenario 10 remains the best for all weight value combinations within the range. This further supports that the optimal solution, for the given scenarios, is not sensitive to these two weights.

	W_{Dist}										
W_{AC} or W_{WX}	0	2	4	6	8	10	12	14	16	18	20
0	9	9	9	9	9	10	10	10	10	10	10
1	9	9	9	9	9	10	10	10	10	10	10
2	9	9	9	9	9	10	10	10	10	10	10
3	9	9	9	9	9	10	10	10	10	10	10
4	9	9	9	9	9	10	10	10	10	10	10
5	9	9	9	9	9	10	10	10	10	10	10
6	9	9	9	9	9	10	10	10	10	10	10
7	9	9	9	9	9	10	10	10	10	10	10
8	9	9	9	9	9	10	10	10	10	10	10
9	9	9	9	9	9	10	10	10	10	10	10
10	9	9	9	9	9	10	10	10	10	10	10

Figure 4.10 – Two-Way Analysis of W_{Dist} with either W_{AC} or W_{WX}

	W_{MP}										
W_{AC} or W_{WX}	0	1	2	3	4	5	6	7	8	9	10
0	10	10	10	10	9	9	8	8	8	8	8
1	10	10	10	10	9	9	8	8	8	8	8
2	10	10	10	10	9	9	8	8	8	8	8
3	10	10	10	10	9	9	8	8	8	8	8
4	10	10	10	10	9	9	8	8	8	8	8
5	10	10	10	10	9	9	8	8	8	8	8
6	10	10	10	10	9	9	8	8	8	8	8
7	10	10	10	10	9	9	8	8	8	8	8
8	10	10	10	10	9	9	8	8	8	8	8
9	10	10	10	10	9	9	8	8	8	8	8
10	10	10	10	10	9	9	8	8	8	8	8

Figure 4.11 – Two-Way Analysis of W_{MP} with either W_{AC} or W_{WX}

	W_{MM}										
W_{AC} or W_{WX}	0	1	2	3	4	5	6	7	8	9	10
0	10	10	9	9	9	9	9	9	9	9	9
1	10	10	9	9	9	9	9	9	9	9	9
2	10	10	9	9	9	9	9	9	9	9	9
3	10	10	9	9	9	9	9	9	9	9	9
4	10	10	9	9	9	9	9	9	9	9	9
5	10	10	9	9	9	9	9	9	9	9	9
6	10	10	9	9	9	9	9	9	9	9	9
7	10	10	9	9	9	9	9	9	9	9	9
8	10	10	9	9	9	9	9	9	9	9	9
9	10	10	9	9	9	9	9	9	9	9	9
10	10	10	9	9	9	9	9	9	9	9	9

Figure 4.12 – Two-Way Analysis of W_{MM} with either W_{AC} or W_{WX}

4.3.10 Feasibility Analysis of Manpower Lower Bounds

A final analysis looks at scenario feasibility based on lower bound values for key career fields ($IC_C \geq 5$) in the Manpower objective. This analysis first summarizes the key career field's $Z^{MP}{}_C$ values, which reflect the minimum score for the given Career Field, *C*. Figure 4.13 provides this summary. Next, the analysis multiplies and rounds up the $CO_{Best,C}$ values across a range of zero to 100%, as shown in Figure 4.14. Finally, each scenario's $Z^{MP}{}_C$ values are compared against the $CO_{Best,C}$ percentage values to determine

the range of feasibility, as shown in Figure 4.14. This analysis shows that while all scenarios do meet the current lower bound constraint, only six are feasible when that lower bound increases above 10% of the current values. This highlights some concern about establishing acceptable lower bounds; however, it is reassuring that the top four valued scenarios are feasible with a 20% to 40% increase in the manpower lower bounds.

			Z^{MP}_{C} Values for Scenario									
Career Field, C	IC_C	$CO_{Best,C}$	10	9	8	7	6	5	4	3	2	1
Officer	**8**	18	**15**	**15**	**15**	**15**	**0**	**0**	**12**	**8**	**7**	**15**
Electric	**6**	34	**35**	**26**	**27**	**20**	**26**	**18**	**20**	**20**	**20**	**35**
Power Pro	**6**	29	**32**	**13**	**14**	**14**	**5**	**5**	**11**	**5**	**2**	**17**
HVAC	**6**	38	**34**	**25**	**41**	**34**	**22**	**22**	**34**	**22**	**6**	**44**
Pavements	**6**	22	**6**	**23**	**17**	**7**	**15**	**4**	**12**	**0**	**22**	**23**
Struct	**6**	36	**22**	**24**	**42**	**17**	**28**	**27**	**17**	**31**	**31**	**37**
Utilities	**6**	33	**26**	**35**	**41**	**8**	**20**	**20**	**24**	**1**	**16**	**40**
EA	**8**	24	**21**	**25**	**25**	**15**	**15**	**12**	**17**	**16**	**17**	**23**

Figure 4.13 – Summary of Z^{MP}_{C} Values

	Percent of $CO_{Best,C}$										
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Officer	**0**	**2**	**4**	**6**	**8**	**9**	**11**	**13**	**15**	**17**	**18**
Electric	**0**	**4**	**7**	**11**	**14**	**17**	**21**	**24**	**28**	**31**	**34**
Power Pro	**0**	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**29**
HVAC	**0**	**4**	**8**	**12**	**16**	**19**	**23**	**27**	**31**	**35**	**38**
Pavements	**0**	**3**	**5**	**7**	**9**	**11**	**14**	**16**	**18**	**20**	**22**
Struct	**0**	**4**	**8**	**11**	**15**	**18**	**22**	**26**	**29**	**33**	**36**
Utilities	**0**	**4**	**7**	**10**	**14**	**17**	**20**	**24**	**27**	**30**	**33**
EA	**0**	**3**	**5**	**8**	**10**	**12**	**15**	**17**	**20**	**22**	**24**

Figure 4.14 – $CO_{Best,C}$ Percentage Values

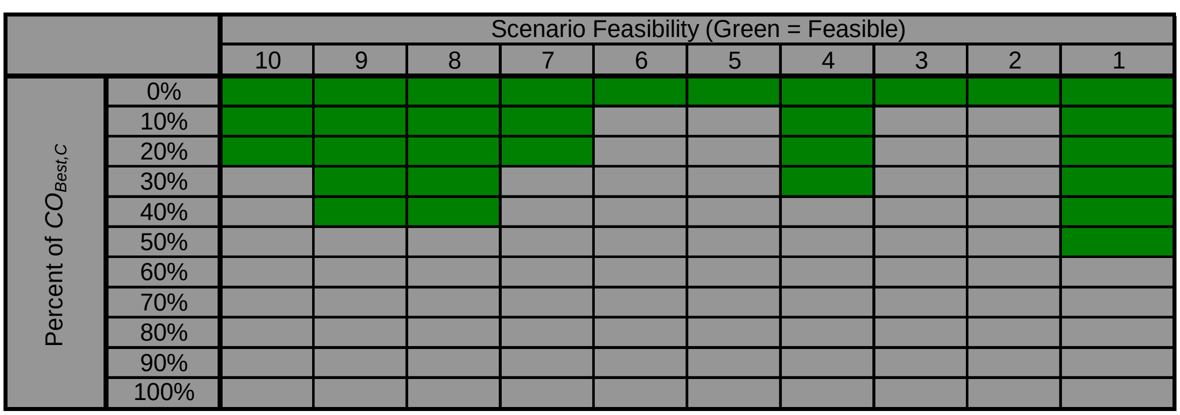


Figure 4.15 – Feasibility Range Due to Key Career Field Lower Bounds

4.4 Summary

The overall observation from these results is that, given the scenarios used, the objective function is significantly sensitive to the values of W_{Dist}, W_{MP}, and W_{MM}. However, it is also noteworthy that throughout each analysis, when Scenario 10 did not have the best *OF* value, Scenario 9 usually did; and on a few occasions, the best solution was Scenario 8. This is a logical occurrence, since Section 4.2 already identifies Scenarios 9 and 8 as the second and third best alternatives. The feasibility analysis reemphasizes this point by demonstrating these scenarios's superior range of feasibility. Ultimately, the determination of the best alternative comes down to a visual examination of the top three scenarios to determine which demonstrates the most desirable traits. In doing so, this research concludes that Scenario 10 is the best alternative. To reinforce this claim, Figure 4.16 below shows potential regions for use with Scenario 10.

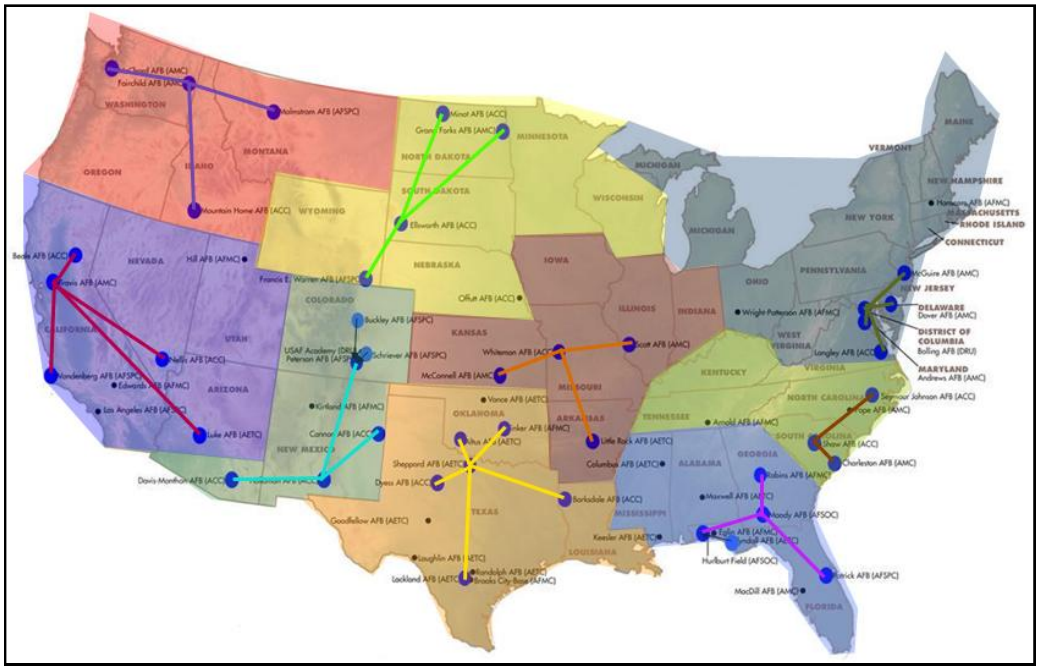


Figure 4.16 - Hub-and-Spoke Regions Based on Scenario 10

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Chapter Overview

Chapter 5 presents any conclusions made based on the findings, and provides recommendations for both future research and applications of the model.

5.2 Conclusions

The objective of this research was to explore the practicality of a new AEF alternative for the CE career field that both meets deployment requirements and improves the overall home-station and deployed location effectiveness. Chapter 2 identified which organizational behavior variables that a new deployment paradigm should focus on to generate the desired results. By creating a paradigm that employs hub-and-spoke networks, each supporting a single FOB, CE benefits from a reemphasis on teaming, mission ownership, and minimized loss of manpower. The challenge in this research was to develop an LP model that could generate alternatives that meet the minimum requirement. Chapter 3 shows how this model was built, employing the programming logic of a transshipment model. Chapter 4 then explores the effectiveness and sensitivity of this model, and builds a case for the best scenario. While the model clearly cannot maximize all objectives in the model, it does generate acceptable scenarios to build upon. This research shows that the hub-and-spoke network paradigm is worth consideration as it is both feasible and it presents a number of benefits for the CE community. However, the paradigm also poses potential drawbacks that require further investigation. This research provides a detailed study on the application of pure hub-and-spoke networks.

5.3 Recommendations for Future Research

Based on the initial success of the model, the next logical steps are to expand the model and improve the data. Expansion poses the challenge of transforming the model into new software packages or solver engines that can tackle a greater number of decision variables and constraints, and improve the model's runtime. By increasing the capacity of the model, it should be able to include at a minimum the addition of PACAF and USAFE forces. Improving the data of the model could involve revising the FOB requirements, acquiring more accurate available manpower numbers based either on current UTC posturing or a more recent manpower study. Lastly, inclusion of guard and reserve forces would help immensely in solving for their currently un-quantified impact.

Another direction of expansion for this research is to consider the model for another career field that has a force structure and goals similar to CE. Options for accomplishing this study include independently, depending on the complexity of the career field, or in conjunction with a revised CE study. The benefit of a conjoined study would be the resulting alignment of deployment assignments for both career fields.

Other future research from this study could explore other uses of hub-and-spoke networks for non-deployment issues such as collaborative training, equipment consolidation, or shared use of service or construction contracts. Additionally, future researchers may wish to improve upon the objective calculations, to include fine-tuning on the Mission Matching objective calculation.

5.4 Recommendations for Action

When introducing a new system change, such as the hub-and-spoke paradigm, caution and patience are key factors to success. For a precautionary approach, it would be best to test the new paradigm on a smaller scale, such as selecting only one or two hub-and-spoke networks for a trial period of at least one AEF cycle. The determination of the paradigm's expected benefits are dependent on time, patience, and a reasonable trial period. This research views these elements as critical to achieving an accurate evaluation of the paradigm's success. If the small scale trial is in fact successful, both at meeting requirements and providing the expected benefits, then the recommendation would be to fully implement the paradigm across CE and then explore an expansion to associated career fields such as other expeditionary combat support functions.

5.5 Summary

This research explores the challenges of solving a real world Air Force manpower problem by developing a multi-objective linear programming model. Chapter 1 provides the background and explains the incentive for creating the model. Chapter 2 provides the literature that this research builds upon. Chapter 3 explains the methodology and the model's construction. Chapter 4 shows the model's outputs and provides analysis on its performance. Finally, this chapter sums up the findings and recommendations. It is clear from this effort that Linear Programming is a powerful tool in evaluating the feasibility of alternatives that would be too costly to otherwise test by real-world trial and error. It is also clear that hub-and-spoke networks could present untested alternatives for the military to explore for both deployment and non-deployment issues.

Appendix A

List of Acronyms

AB	Air Base
AEF	Air and Space Expeditionary Force
AFB	Air Force Base
AFI	Air Force Instruction
AFPAM	Air Force Pamphlet
AFSC	Air Force Specialty Code
BCE	Base Civil Engineer
CE	Civil Engineer
CENTAF	USAF, Central Command
CONUS	Continental United States
DA	Decision Analysis
DoD	Department of Defense
DV	Decision Variable
ECS	Expeditionary Combat Support
EOD	Explosive Ordinance Disposal
FOB	Forward Operating Base
HVAC	Heating Ventilation and Air Conditioning
LP	Linear Programming
MAJCOM	Major Command
OCONUS	Other than Continental United States
PACAF	USAF, Pacific Command
PBD	Presidential Budgeting Directive
Prime BEEF	Prime Base Emergency Engineer Force
QDR	Quadrennial Defense Review
SDVF	Single Dimensional Value Function
UDM	Unit Deployment Manager
USAF	United States Air Force
USAFE	USAF, European Command
UTC	Unit Type Code

Appendix B

List of Variables

AO_H	Calculated Airlift objective score at Hub H
AO_{Best}	Best case value used in the SDVF calculation for the Airlift objective
AO_{Worst}	Worst case value used in the SDVF calculation for the Airlift objective
BD_{FC}	Number of personnel from Career Field C needed at Fob F for one bucket
C	Career Field number, value ranges from 1 to j
$CO_{Best,C}$	Best case value used in the SDVF calculation for Career Field C
$CO_{Worst,C}$	Worst case value used in the SDVF calculation for Career Field C
CV_C	Calculated, non-weighted, value earned for Career Field C
d_{SH}	Distance, in miles, between Spoke S and Hub H
DT	Distance Total for the given model solution
DT_{Best}	Factor in the Distance objective calculation; distance earning a value of 1
DT_{Worst}	Factor in the Distance objective calculation, distance earning a value of 0
F	FOB base, ranges from 1 to m
FD_{FC}	Number of personnel FOB F demands from Career Field C for one cycle
FM_{FM}	Binary coded Mission value at FOB F for Mission M
H	Hub base, ranges from 1 to n
HA_H	Calculated total Airlift capability at Hub H
HD_{HC}	Number of personnel Hub H demands from Career Field C for one cycle
HO_{HC}	Number of overage personnel at Hub H for Career Field C for one cycle
HS_{HC}	Number of personnel Hub H supplies for Career Field C for one cycle
HW_H	Calculated total Cold Weather capability at Hub H
i	Number of Missions in the model
IC_C	Magnitude of importance for Career Field C
IM_M	Magnitude of importance for Mission M
j	Number of Career Fields in the model
LB^{AC}	Lower bound for the Z^{AC} DV
LB^{Dist}	Lower bound for the Distance Total DT

$LB^{MM}{}_{M}$	Lower bound for the $Z^{MM}{}_{M}$ DV for Career Field *M*
$LB^{MP}{}_{C}$	Lower bound for the $Z^{MP}{}_{C}$ DV for Career Field *C*
LB^{WX}	Lower bound for the Z^{WX} DV
m	Number of FOBs in the model
M	Mission number, ranges from 1 to *i*
MD_{HM}	Calculated Mission value demanded at Hub *H* for Mission *M*
$MO_{Best,M}$	Best case value used in the SDVF calculation for Mission *M*
MO_{HM}	Calculated Mission value overage at Hub *H* for Mission *M*
$MO_{Worst,M}$	Worst case value used in the SDVF calculation for Mission *M*
MS_{HM}	Calculated Mission value supplied at Hub *H* for Mission *M*
MV_{M}	Calculated, non-weighted, value earned for Mission *M*
n	Number of Home Station bases in the model
$N_{Buckets}$	Number of buckets in one cycle
NF_{AC}	Null Factor used in the Airlift objective
NF_{MM}	Null Factor used in the Mission Matching objective
NF_{MP}	Null Factor used in the Manpower objective
NF_{WX}	Null Factor used in the Weather objective
OF	Objective Function value
OM_{M}	Calculated total Mission overage for Mission *M*
S	Spoke base, ranges from 1 to *n*
SA_{S}	Binary coded Airlift value at Spoke *S*
SM_{SM}	Binary coded Mission value at Spoke *S* for Mission *M*
SS_{SC}	Number of personnel supplied by Spoke *S* for Career Field *C*
SW_{S}	Binary coded Cold Weather value at Spoke *S*
TO_{C}	Total overage calculated for Career Field *C*
UB^{AC}	Upper bound for the Z^{AC} DV
UB^{Dist}	Upper bound for the Distance Total *DT*
$UB^{MM}{}_{M}$	Upper bound for the $Z^{MM}{}_{M}$ DV for Career Field *M*
$UB^{MP}{}_{C}$	Upper bound for the $Z^{MP}{}_{C}$ DV for Career Field *C*
UB^{WX}	Upper bound for the Z^{WX} DV

V_{AC}	Value earned for the Airlift objective
V_{Dist}	Value earned for the Distance objective
V_{MM}	Value earned for the Mission Matching objective
V_{MP}	Value earned for the Manpower objective
V_{WX}	Value earned for the Weather objective
W_{AC}	Weight given to the Airlift objective
W_{Dist}	Weight given to the Distance objective
W_{MM}	Weight given to the Mission Matching objective
W_{MP}	Weight given to the Manpower objective
WO_{Best}	Best case value used in the SDVF calculation for the Weather objective
WO_H	Calculated Weather objective score at Hub H
WO_{Worst}	Worst case value used in the SDVF calculation for the Weather objective
W_{WX}	Weight given to the Weather objective
X_{SH}	DV, links Spoke S to Hub H
X_{HH}	Specific instance of the DV X_{SH}, where $S = H$, thus indicating a Hub DV
Y_{HF}	DV, links Hub H to FOB F
Z^{AC}	Airlift objective DV that denotes the smallest airlift value
$Z^{MM}{}_M$	Mission Matching DV that denotes the smallest overage for Mission M
$Z^{MP}{}_C$	Manpower DV that denotes the smallest overage for Career Field C
Z^{WX}	Weather objective DV that denotes the smallest cold weather value

Scenario 1: Objective Function = 0.25394 (Test Model C5)

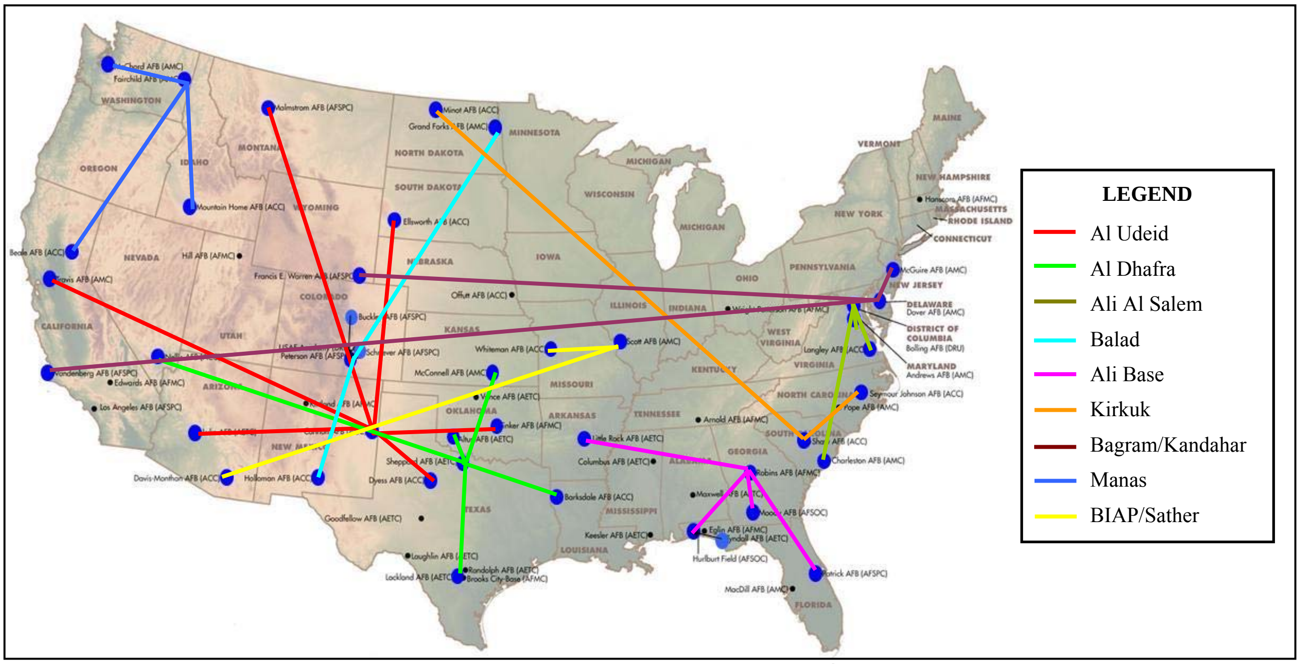


Figure C.1 - Hub-and-Spoke Networks for Scenario 1

Table C.1 – Summary of Scenario 1 Solution

FOB	Al Udeid	Al Dhafra	Ali Al Salem	Balad	Ali Base	Kirkuk	Bagram/Kandahar	Manas	BIAP/Sather
Hub	Cannon	Sheppard	Bolling	Peterson (SchrieverBuckley)	Robins	Shaw	Dover	Fairchild	Scott
Spokes	Dyess, Ellsworth, Luke, Malmstrom, Tinker, Travis	Altus, Barksdale, Lackland, McConnell, Nellis	Andrews, Charleston, Langley	Grand Forks, Holloman	HurlburtFld (Tyndall), Little Rock, Moody, Patrick	Minot, Seymour Johnson	FE Warren, McGuire, Vandenberg	Beale, McChord, Mt Home	Davis Monthan, Whiteman
Total Distance	4822	2203	721	1607	1531	1966	4735	1702	1740
Max Distance	1322	1083	534	1115	628	1760	2893	919	1510
Average Distance	688.9	367.2	180.3	535.7	306.2	655.3	1183.8	425.5	580.0
FOB Mission	KC135, KC10, C130, F15	KC10	C130	C130, F16, A10	C130	NA	C130, F15, A10	KC135, C17	C130, C17
H-S Missions	KC135(1), KC10(2), C130(1), C17(1), F16(2)	KC135(2), C17(1), F15(1), F16(2), A10(2)	KC135(1), C17(1), F15(1), F16(2), A10(1)	KC135(1), C130(1), F16(1)	KC135(1), C130(4), C17(1), F15(2), A10(1)	KC135(1), F15(1), F16(1)	KC10(1), C17(1)	KC135(2), C17(1), F15(1), F16(1)	KC135(1), A10(2)
Airlift Count	3	2	2	2	3	1	2	3	1
Cold Wx H-S Bases	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2	N/A
Officers Required	30	9	21	18	12	18	6	15	12
Officers Supplied	50	45	47	41	58	33	36	34	33
Chiefs Required	3	3	6	3	3	3	0	3	3
Chiefs Supplied	8	7	7	5	8	4	5	4	3
Supert Required	12	9	12	15	15	12	0	12	9
Supert Supplied	40	28	26	25	24	23	23	21	19
FrstSgt Required	3	3	3	3	3	3	0	3	3
FrstSgt Supplied	9	7	6	6	6	5	4	4	3
Supply Required	18	6	6	12	6	6	6	6	6
Supply Supplied	32	19	18	17	17	13	16	16	17
Electric Required	96	30	24	45	24	24	15	21	21
Electric Supplied	131	121	78	90	71	67	96	64	56
PowerPro Required	30	21	48	66	48	12	18	6	36
PowerPro Supplied	140	66	75	83	101	71	60	55	54
HVAC Required	108	27	36	45	27	27	0	27	27
HVAC Supplied	152	106	99	95	85	93	66	80	72
Pavements Required	96	24	24	48	36	24	60	24	24
Pavements Supplied	138	77	90	71	61	83	93	73	54
Structures Required	87	21	24	36	21	24	15	30	21
Structures Supplied	129	93	75	104	70	76	81	69	58
Utilities Required	102	24	30	54	27	39	0	24	24
Utilities Supplied	142	88	91	96	72	81	92	73	71
LiqFuels Required	0	6	6	6	0	0	0	0	6
LiqFuels Supplied	31	25	14	15	14	12	13	16	15
PestMgmt Required	6	6	6	6	6	6	0	6	6
PestMgmt Supplied	20	18	14	13	9	14	11	9	10
EA Required	42	9	24	15	9	15	12	9	9
EA Supplied	73	49	49	38	60	48	40	38	36
OpsMgmt Required	18	6	9	12	6	9	0	6	6
OpsMgmt Supplied	28	31	17	20	12	15	9	17	13

Scenario 2: Objective Function = 0.30607 (Test Model C1)

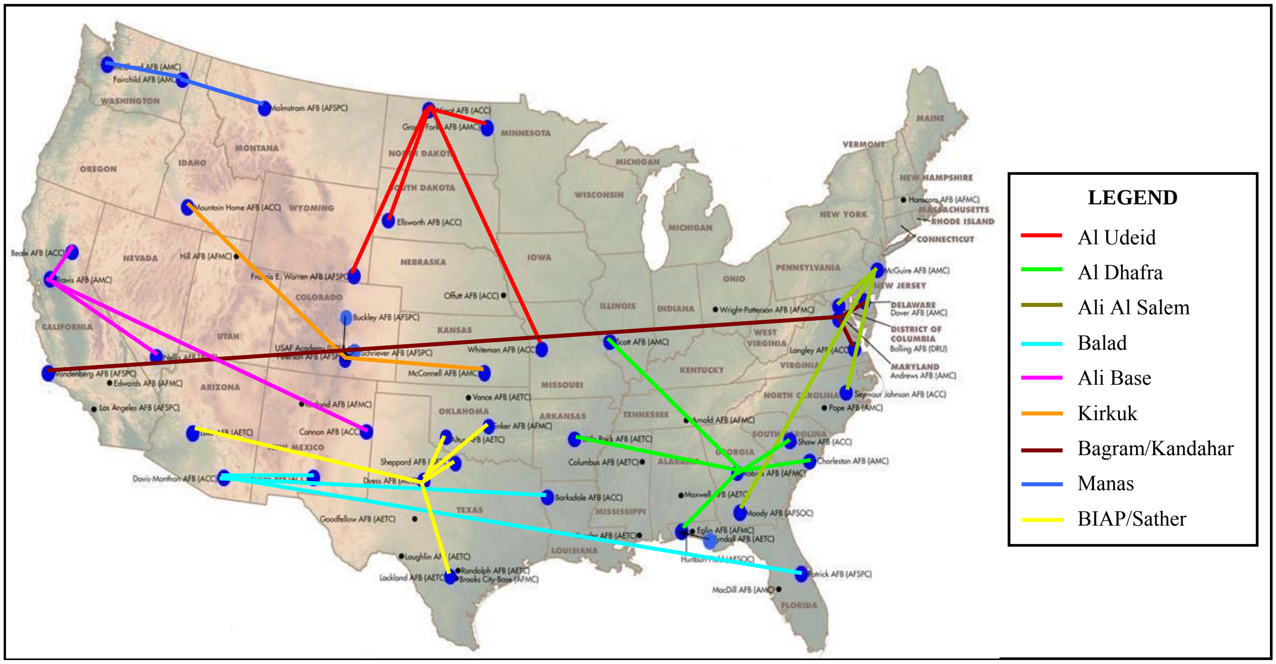


Figure C.2 - Hub-and-Spoke Networks for Scenario 2

Table C.2 – Summary of Scenario 2 Solution

FOB	Al Udeid	Al Dhafra	Ali Al Salem	Balad	Ali Base	Kirkuk	Bagram/Kandahar	Manas	BIAP/Sather
Hub	Minot	Robins	McGuire	Davis Monthan	Travis	Peterson (SchrieverBuckley)	Andrews	Fairchild	Dyess
Spokes	Ellsworth, FE Warren, Grand Forks, Whiteman	Charleston, HurlburtFld (Tyndall), Little Rock, Scott, Shaw	Bolling, Moody, Seymour Johnson	Barksdale, Holloman, Patrick	Beale, Cannon, Nellis	McConnell, Mt Home	Dover, Langley, Vandenberg	Malmstrom, McChord	Altus, Lackland, Luke, Sheppard, Tinker
Total Distance	2341	2131	1544	3552	2015	1382	3109	729	1889
Max Distance	953	639	914	2081	1322	875	2834	418	900
Average Distance	468.2	355.2	386.0	888.0	503.8	460.7	777.3	243.0	314.8
FOB Mission	KC135, KC10, C130, F15	KC10	C130	C130, F16, A10	C130	NA	C130, F15, A10	KC135, C17	C130, C17
H-S Missions	KC135(1), A10(1)	KC135(2), C130(3), C17(2), F15(2), F16(1)	KC135(1), KC10(1), C17(1), F15(1), A10(1)	C130(1), A10(2)	KC135(1), KC10(1), C17(1), F15(1), F16(2), A10(1)	KC135(1), C130(1), F15(1), F16(2)	KC135(1), F15(1), F16(2), A10(1)	KC135(1), C17(1)	KC135(2), KC10(1), C130(1), C17(1), F16(2)
Airlift Count	1	4	2	1	2	2	2	2	3
Cold Wx H-S Bases	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2	N/A
Officers Required	30	9	21	18	12	18	6	15	12
Officers Supplied	44	77	43	44	41	37	38	22	31
Chiefs Required	3	3	6	3	3	3	0	3	3
Chiefs Supplied	7	9	6	5	6	4	6	3	5
Supert Required	12	9	12	15	15	12	0	12	9
Supert Supplied	34	34	21	28	30	16	29	15	22
FrstSgt Required	3	3	3	3	3	3	0	3	3
FrstSgt Supplied	7	8	4	6	6	4	6	3	6
Supply Required	18	6	6	12	6	6	6	6	6
Supply Supplied	25	33	16	14	22	14	18	9	14
Electric Required	96	30	24	45	24	24	15	21	21
Electric Supplied	116	92	69	92	97	62	104	58	84
PowerPro Required	30	21	48	66	48	12	18	6	36
PowerPro Supplied	77	134	50	107	95	31	92	32	87
HVAC Required	108	27	36	45	27	27	0	27	27
HVAC Supplied	114	140	57	122	125	46	104	41	99
Pavements Required	96	24	24	48	36	24	60	24	24
Pavements Supplied	118	89	84	79	92	55	104	67	52
Structures Required	87	21	24	36	21	24	15	30	21
Structures Supplied	118	89	65	111	91	55	97	63	66
Utilities Required	102	24	30	54	27	39	0	24	24
Utilities Supplied	135	105	75	103	99	55	113	56	65
LiqFuels Required	0	6	6	6	0	0	0	0	6
LiqFuels Supplied	27	21	12	15	25	12	15	11	17
PestMgmt Required	6	6	6	6	6	6	0	6	6
PestMgmt Supplied	18	16	15	14	14	8	12	9	12
EA Required	42	9	24	15	9	15	12	9	9
EA Supplied	68	75	52	42	51	32	46	31	34
OpsMgmt Required	18	6	9	12	6	9	0	6	6
OpsMgmt Supplied	24	19	15	18	20	16	13	12	25

Appendix C

Scenario 3: Objective Function = 0.68044 (Test Model B5)

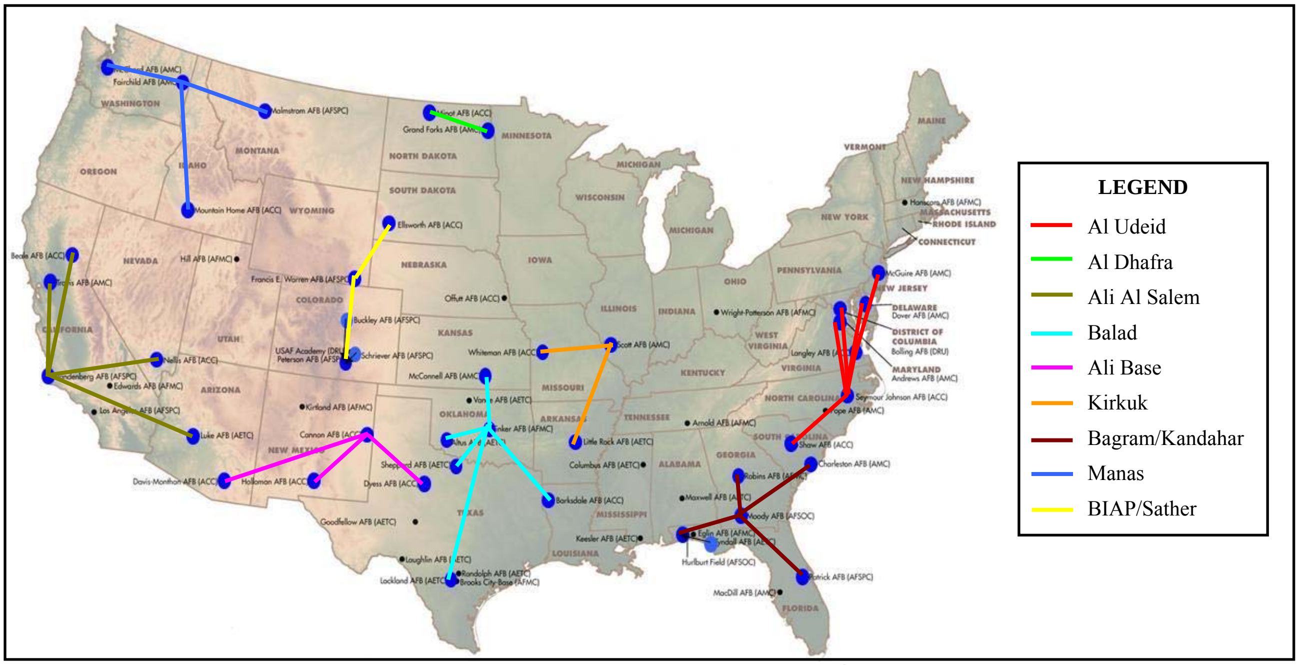


Figure C.3 - Hub-and-Spoke Networks for Scenario 3

Table C.3 – Summary of Scenario 3 Solution

FOB	Al Udeid	Al Dhafra	Ali Al Salem	Balad	Ali Base	Kirkuk	Bagram/Kandahar	Manas	BIAP/Sather
Hub	Seymour Johnson	Grand Forks	Vandenberg	Tinker	Cannon	Scott	Moody	Fairchild	FE Warren
Spokes	Andrews, Bolling, Dover, Langley, McGuire, Shaw	Minot	Beale, Luke, Nellis, Travis	Altus, Barksdale, Lackland, McConnell, Sheppard	Davis Monthan, Dyess, Holloman	Little Rock, Whiteman	Charleston, HurlburtFld (Tyndall), Patrick, Robins	Malmstrom, McChord, Mt Home	Ellsworth, Peterson (SchrieverBuckley)
Total Distance	1810	215	1673	1341	1054	660	946	1201	514
Max Distance	454	215	518	483	561	430	287	472	330
Average Distance	258.6	107.5	334.6	223.5	263.5	220.0	189.2	300.3	171.3
FOB Mission	KC135, KC10, C130, F15	KC10	C130	C130, F16, A10	C130	NA	C130, F15, A10	KC135, C17	C130, C17
H-S Missions	KC135(2), KC10(1), C17(1), F15(2), F16(3), A10(1)	KC135(1)	KC135(1), KC10(1), C17(1), F15(1), F16(2), A10(1)	KC135(3), KC10(1), C17(1), F16(1), A10(1)	C130(1), F16(1), A10(1)	KC135(1), C130(1), A10(1)	KC135(1), C130(3), C17(2), F15(2), A10(1)	KC135(1), C17(1), F15(1), F16(1)	C130(1), F16(1)
Airlift Count	4	1	2	3	1	2	3	2	1
Cold Wx H-S Bases	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3	N/A
Officers Required	30	9	21	18	12	18	6	15	12
Officers Supplied	79	18	47	34	46	26	57	31	39
Chiefs Required	3	3	6	3	3	3	0	3	3
Chiefs Supplied	11	3	7	5	5	3	8	4	5
Supert Required	12	9	12	15	15	12	0	12	9
Supert Supplied	47	15	36	22	29	16	24	20	20
FrstSgt Required	3	3	3	3	3	3	0	3	3
FrstSgt Supplied	10	3	7	6	6	3	6	4	5
Supply Required	18	6	6	12	6	6	6	6	6
Supply Supplied	36	12	27	14	16	18	16	13	13
Electric Required	96	30	24	45	24	24	15	21	21
Electric Supplied	144	50	131	95	87	47	76	73	71
PowerPro Required	30	21	48	66	48	12	18	6	36
PowerPro Supplied	145	33	116	86	107	35	101	41	41
HVAC Required	108	27	36	45	27	27	0	27	27
HVAC Supplied	175	49	144	87	128	59	85	61	60
Pavements Required	96	24	24	48	36	24	60	24	24
Pavements Supplied	161	49	124	48	88	49	63	86	72
Structures Required	87	21	24	36	21	24	15	30	21
Structures Supplied	148	52	109	60	113	60	64	77	72
Utilities Required	102	24	30	54	27	39	0	24	24
Utilities Supplied	165	59	128	55	112	66	77	76	68
LiqFuels Required	0	6	6	6	0	0	0	0	6
LiqFuels Supplied	26	10	23	20	18	15	14	14	15
PestMgmt Required	6	6	6	6	6	6	0	6	6
PestMgmt Supplied	28	8	16	11	14	9	10	11	11
EA Required	42	9	24	15	9	15	12	9	9
EA Supplied	88	30	63	31	43	36	58	38	44
OpsMgmt Required	18	6	9	12	6	9	0	6	6
OpsMgmt Supplied	28	10	18	25	24	12	12	17	16

Scenario 4: Objective Function = 0.68811 (Test Model E1)

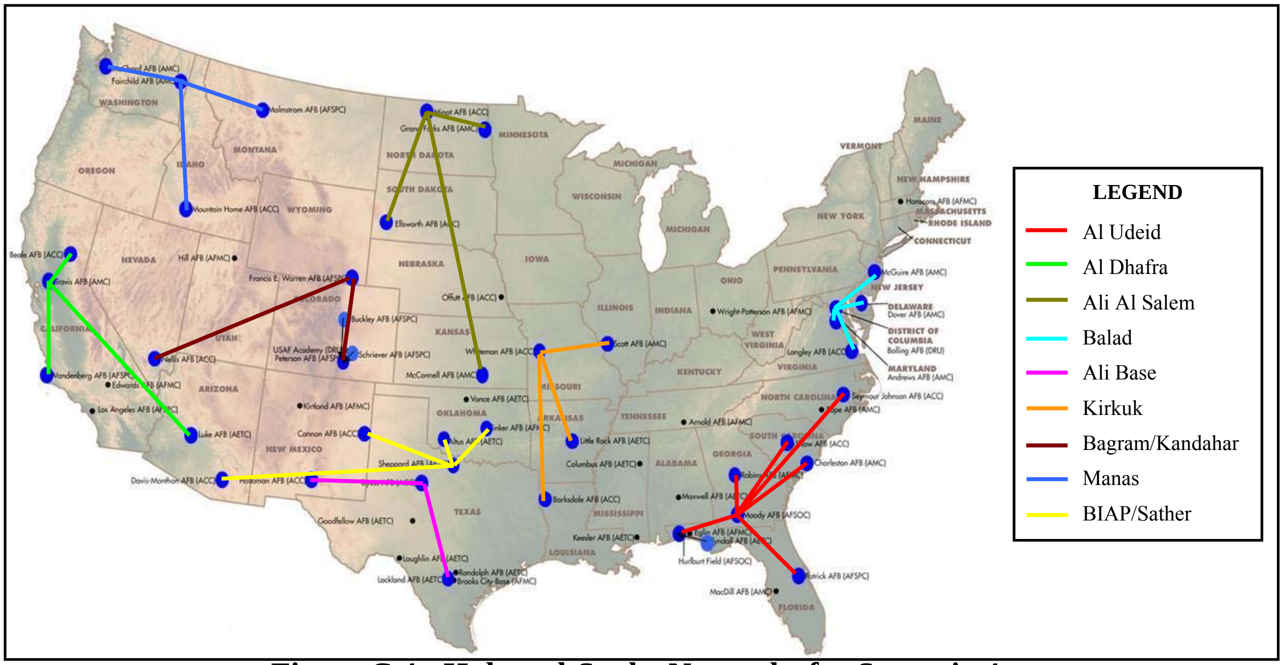


Figure C.4 - Hub-and-Spoke Networks for Scenario 4

Table C.4 – Summary of Scenario 4 Solution

FOB	Al Udeid	Al Dhafra	Ali Al Salem	Balad	Ali Base	Kirkuk	Bagram/Kandahar	Manas	BIAP/Sather
Hub	Moody	Travis	Minot	Bolling	Dyess	Whiteman	FE Warren	Fairchild	Sheppard
Spokes	Charleston, HurlburtFld (Tyndall), Patrick, Robins, Seymour Johnson, Shaw	Beale, Luke, Vandenberg	Ellsworth, Grand Forks, McConnell	Andrews, Dover, Langley, McGuire	Holloman, Lackland	Barksdale, Little Rock, Scott	Nellis, Peterson (SchrieverBuckley)	Malmstrom, McChord, Mt Home	Altus, Cannon, Davis Monthan, Tinker
Total Distance	1745	1167	1672	462	685	1135	1024	1201	1446
Max Distance	487	757	994	176	413	556	840	472	916
Average Distance	249.3	291.8	418.0	92.4	228.3	283.8	341.3	300.3	289.2
FOB Mission	KC135, KC10, C130, F15	KC10	C130	C130, F16, A10	C130	NA	C130, F15, A10	KC135, C17	C130, C17
H-S Missions	KC135(2), C130(3), C17(2), F15(3), F16(1), A10(1)	KC135(1), KC10(1), C17(1), F16(1)	KC135(2)	KC135(1), KC10(1), C17(1), F15(1), F16(2), A10(1)	C130(1), F16(1)	KC135(1), C130(1), A10(2)	C130(1), F15(1), F16(2), A10(1)	KC135(1), C17(1), F15(1), F16(1)	KC135(2), KC10(1), C17(1), F16(1), A10(1)
Airlift Count	4	2	2	3	2	2	1	2	1
Cold Wx H-S Bases	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3	N/A
Officers Required	30	9	21	18	12	18	6	15	12
Officers Supplied	80	36	34	56	24	36	41	31	39
Chiefs Required	3	3	6	3	3	3	0	3	3
Chiefs Supplied	10	5	6	9	4	4	5	4	4
Supert Required	12	9	12	15	15	12	0	12	9
Supert Supplied	38	27	27	33	20	21	21	20	22
FrstSgt Required	3	3	3	3	3	3	0	3	3
FrstSgt Supplied	9	5	6	7	5	4	5	4	5
Supply Required	18	6	6	12	6	6	6	6	6
Supply Supplied	25	22	24	27	10	24	11	13	9
Electric Required	96	30	24	45	24	24	15	21	21
Electric Supplied	116	105	96	104	78	63	72	73	67
PowerPro Required	30	21	48	66	48	12	18	6	36
PowerPro Supplied	154	92	59	92	65	47	48	41	107
HVAC Required	108	27	36	45	27	27	0	27	27
HVAC Supplied	144	103	87	116	97	74	74	61	92
Pavements Required	96	24	24	48	36	24	60	24	24
Pavements Supplied	114	95	90	110	51	66	72	86	56
Structures Required	87	21	24	36	21	24	15	30	21
Structures Supplied	104	76	92	108	95	77	77	77	49
Utilities Required	102	24	30	54	27	39	0	24	24
Utilities Supplied	126	95	102	116	72	86	72	76	61
LiqFuels Required	0	6	6	6	0	0	0	0	6
LiqFuels Supplied	22	18	21	18	10	20	13	14	19
PestMgmt Required	6	6	6	6	6	6	0	6	6
PestMgmt Supplied	20	9	14	18	8	13	14	11	11
EA Required	42	9	24	15	9	15	12	9	9
EA Supplied	84	44	59	62	32	44	42	38	26
OpsMgmt Required	18	6	9	12	6	9	0	6	6
OpsMgmt Supplied	21	12	20	19	24	16	16	17	17

Scenario 5: Objective Function = 0.69512 (Test Model B6)

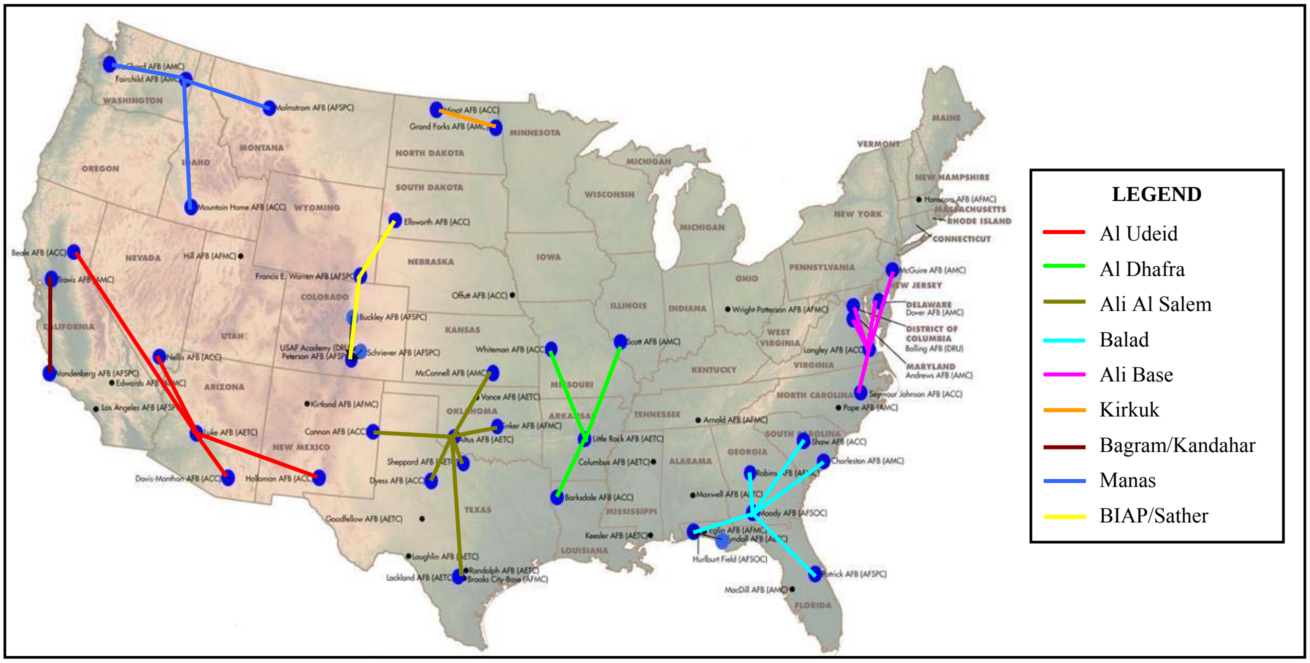


Figure C.5 - Hub-and-Spoke Networks for Scenario 5

Table C.5 – Summary of Scenario 5 Solution

FOB	Al Udeid	Al Dhafra	Ali Al Salem	Balad	Ali Base	Kirkuk	Bagram/Kandahar	Manas	BIAP/Sather
Hub	Luke	Little Rock	Altus	Moody	Langley	Grand Forks	Travis	Fairchild	FE Warren
Spokes	Beale, Davis Monthan, Holloman, Nellis	Barksdale, Scott, Whiteman	Cannon, Dyess, Lackland, McConnell, Sheppard, Tinker	Charleston, HurlburtFld (Tyndall), Patrick, Robins, Shaw	Andrews, Bolling, Dover, McGuire, Seymour Johnson	Minot	Vandenberg	Malmstrom, McChord, Mt Home	Ellsworth, Peterson (SchrieverBuckley)
Total Distance	1685	1012	1418	1258	1106	215	318	1201	514
Max Distance	796	430	410	312	346	215	318	472	330
Average Distance	337.0	253.0	202.6	209.7	184.3	107.5	159.0	300.3	171.3
FOB Mission	KC135, KC10, C130, F15	KC10	C130	C130, F16, A10	C130	NA	C130, F15, A10	KC135, C17	C130, C17
H-S Missions	KC135(1), F15(1), F16(2), A10(2)	KC135(1), C130(1), A10(2)	KC135(3), KC10(1), C130(1), C17(1), F16(2)	KC135(1), C130(3), C17(2), F15(2), F16(1), A10(1)	KC135(2), KC10(1), C17(1), F15(2), F16(2), A10(1)	KC135(1)	KC10(1), C17(1)	KC135(1), C17(1), F15(1), F16(1)	C130(1), F16(1)
Airlift Count	1	2	4	3	4	1	1	2	1
Cold Wx H-S Bases	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0	N/A
Officers Required	30	9	21	18	12	18	6	15	12
Officers Supplied	55	36	42	72	64	18	20	31	39
Chiefs Required	3	3	6	3	3	3	0	3	3
Chiefs Supplied	7	4	6	9	10	3	3	4	5
Supert Required	12	9	12	15	15	12	0	12	9
Supert Supplied	39	21	27	32	39	15	16	20	20
FrstSgt Required	3	3	3	3	3	3	0	3	3
FrstSgt Supplied	8	4	7	8	8	3	3	4	5
Supply Required	18	6	6	12	6	6	6	6	6
Supply Supplied	23	24	16	21	31	12	12	13	13
Electric Required	96	30	24	45	24	24	15	21	21
Electric Supplied	114	63	107	98	122	50	76	73	71
PowerPro Required	30	21	48	66	48	12	18	6	36
PowerPro Supplied	145	47	99	139	107	33	53	41	41
HVAC Required	108	27	36	45	27	27	0	27	27
HVAC Supplied	186	74	107	127	133	49	51	61	60
Pavements Required	96	24	24	48	36	24	60	24	24
Pavements Supplied	108	66	71	91	133	49	64	86	72
Structures Required	87	21	24	36	21	24	15	30	21
Structures Supplied	145	77	78	81	131	52	42	77	72
Utilities Required	102	24	30	54	27	39	0	24	24
Utilities Supplied	140	86	79	101	141	59	56	76	68
LiqFuels Required	0	6	6	6	0	0	0	0	6
LiqFuels Supplied	18	20	25	18	22	10	13	14	15
PestMgmt Required	6	6	6	6	6	6	0	6	6
PestMgmt Supplied	21	13	13	14	24	8	3	11	11
EA Required	42	9	24	15	9	15	12	9	9
EA Supplied	63	44	42	71	75	30	24	38	44
OpsMgmt Required	18	6	9	12	6	9	0	6	6
OpsMgmt Supplied	27	16	31	16	24	10	5	17	16

Scenario 6: Objective Function = 0.69874 (Test Model B4)

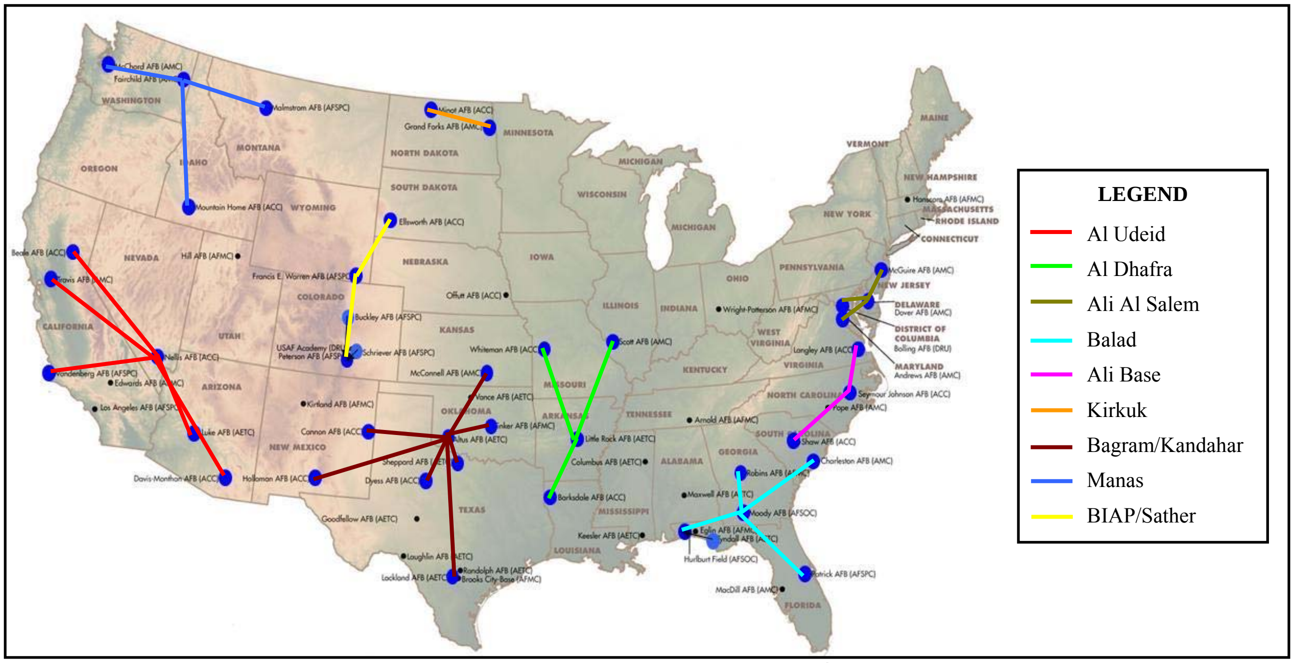


Figure C.6 - Hub-and-Spoke Networks for Scenario 6

Table C.6 – Summary of Scenario 6 Solution

FOB	Al Udeid	Al Dhafra	Ali Al Salem	Balad	Ali Base	Kirkuk	Bagram/Kandahar	Manas	BIAP/Sather
Hub	Nellis	Little Rock	Dover	Moody	Seymour Johnson	Grand Forks	Altus	Fairchild	FE Warren
Spokes	Beale, Davis Monthan, Luke, Travis, Vandenberg	Barksdale, Scott, Whiteman	Andrews, Bolling, McGuire	Charleston, HurlburtFld (Tyndall), Patrick, Robins	Langley, Shaw	Minot	Cannon, Dyess, Holloman, Lackland, McConnell, Sheppard, Tinker	Malmstrom, McChord, Mt Home	Ellsworth, Peterson (SchrieverBuckley)
Total Distance	2341	1012	313	946	404	215	1962	1201	514
Max Distance	614	430	119	287	206	215	544	472	330
Average Distance	390.2	253.0	78.3	189.2	134.7	107.5	245.3	300.3	171.3
FOB Mission	KC135, KC10, C130, F15	KC10	C130	C130, F16, A10	C130	NA	C130, F15, A10	KC135, C17	C130, C17
H-S Missions	KC135(1), KC10(1), C17(1), F15(1), F16(2), A10(2)	KC135(1), C130(1), A10(2)	KC135(1), KC10(1), C17(1), F16(1)	KC135(1), C130(3), C17(2), F15(2), A10(1)	KC135(1), F15(2), F16(2), A10(1)	KC135(1)	KC135(3), KC10(1), C130(1), C17(1), F16(2)	KC135(1), C17(1), F15(1), F16(1)	C130(1), F16(1)
Airlift Count	2	2	3	3	1	1	4	2	1
Cold Wx H-S Bases	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3	N/A
Officers Required	30	9	21	18	12	18	6	15	12
Officers Supplied	63	36	46	57	33	18	54	31	39
Chiefs Required	3	3	6	3	3	3	0	3	3
Chiefs Supplied	8	4	7	8	4	3	8	4	5
Supert Required	12	9	12	15	15	12	0	12	9
Supert Supplied	43	21	24	24	23	15	39	20	20
FrstSgt Required	3	3	3	3	3	3	0	3	3
FrstSgt Supplied	8	4	5	6	5	3	10	4	5
Supply Required	18	6	6	12	6	6	6	6	6
Supply Supplied	31	24	21	16	15	12	20	13	13
Electric Required	96	30	24	45	24	24	15	21	21
Electric Supplied	149	63	82	76	62	50	148	73	71
PowerPro Required	30	21	48	66	48	12	18	6	36
PowerPro Supplied	143	47	62	101	83	33	154	41	41
HVAC Required	108	27	36	45	27	27	0	27	27
HVAC Supplied	172	74	68	85	107	49	172	61	60
Pavements Required	96	24	24	48	36	24	60	24	24
Pavements Supplied	142	66	83	63	78	49	101	86	72
Structures Required	87	21	24	36	21	24	15	30	21
Structures Supplied	128	77	83	64	65	52	137	77	72
Utilities Required	102	24	30	54	27	39	0	24	24
Utilities Supplied	148	86	88	77	77	59	127	76	68
LiqFuels Required	0	6	6	6	0	0	0	0	6
LiqFuels Supplied	27	20	14	14	12	10	29	14	15
PestMgmt Required	6	6	6	6	6	6	0	6	6
PestMgmt Supplied	19	13	14	10	14	8	18	11	11
EA Required	42	9	24	15	9	15	12	9	9
EA Supplied	74	44	49	58	39	30	55	38	44
OpsMgmt Required	18	6	9	12	6	9	0	6	6
OpsMgmt Supplied	23	16	14	12	14	10	40	17	16

Scenario 7: Objective Function = 0.72339 (Test Model M2)

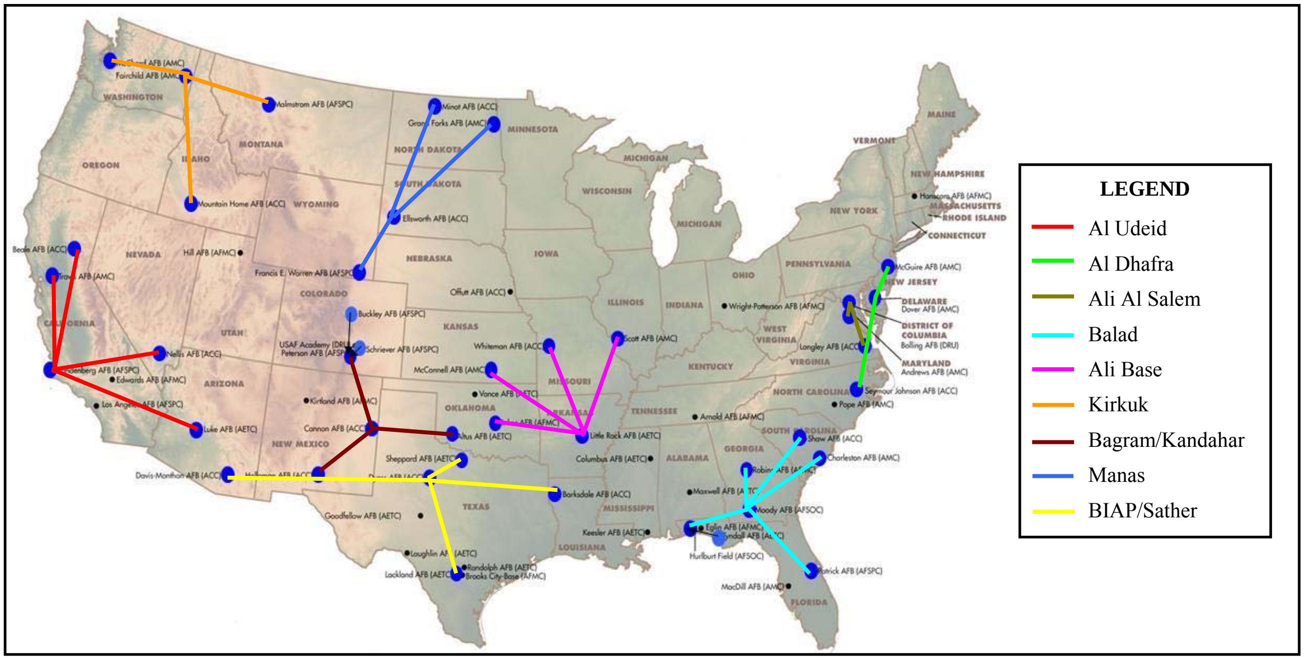


Figure C.7 - Hub-and-Spoke Networks for Scenario 7

Table C.7 – Summary of Scenario 7 Solution

FOB	Al Udeid	Al Dhafra	Ali Al Salem	Balad	Ali Base	Kirkuk	Bagram/Kandahar	Manas	BIAP/Sather
Hub	Vandenberg	Dover	Bolling	Moody	Little Rock	Fairchild	Cannon	Ellsworth	Dyess
Spokes	Beale, Luke, Nellis, Travis	McGuire, Seymour Johnson	Andrews, Langley	Charleston, HurlburtFld (Tyndall), Patrick, Robins, Shaw	McConnell, Scott, Tinker, Whiteman	Malmstrom, McChord, Mt Home	Altus, Holloman, Peterson (SchrieverBuckley)	FE Warren, Grand Forks, Minot	Barksdale, Davis Monthan, Lackland, Sheppard
Total Distance	1673	500	187	1258	1568	1201	955	1444	1582
Max Distance	518	381	175	312	453	472	431	651	759
Average Distance	334.6	166.7	62.3	209.7	313.6	300.3	238.8	361.0	316.4
FOB Mission	KC135, KC10, C130, F15	KC10	C130	C130, F16, A10	C130	NA	C130, F15, A10	KC135, C17	C130, C17
H-S Missions	KC135(1), KC10(1), C17(1), F15(1), F16(2), A10(1)	KC135(1), KC10(1), C17(1), F15(1)	KC135(1), F15(1), F16(2), A10(1)	KC135(1), C130(3), C17(2), F15(2), F16(1), A10(1)	KC135(3), KC10(1), C130(1), A10(1)	KC135(1), C17(1), F15(1), F16(1)	KC135(1), C130(1), C17(1), F16(2)	KC135(1)	C130(1), F16(1), A10(2)
Airlift Count	2	3	1	3	4	2	1	1	2
Cold Wx H-S Bases	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3	N/A
Officers Required	30	9	21	18	12	18	6	15	12
Officers Supplied	47	25	39	72	33	31	51	36	43
Chiefs Required	3	3	6	3	3	3	0	3	3
Chiefs Supplied	7	4	6	9	4	4	6	6	5
Supert Required	12	9	12	15	15	12	0	12	9
Supert Supplied	36	17	22	32	23	20	28	28	23
FrstSgt Required	3	3	3	3	3	3	0	3	3
FrstSgt Supplied	7	3	5	8	5	4	7	6	5
Supply Required	18	6	6	12	6	6	6	6	6
Supply Supplied	27	17	14	21	23	13	14	20	16
Electric Required	96	30	24	45	24	24	15	21	21
Electric Supplied	131	58	64	98	68	73	93	95	94
PowerPro Required	30	21	48	66	48	12	18	6	36
PowerPro Supplied	116	40	67	139	88	41	89	61	64
HVAC Required	108	27	36	45	27	27	0	27	27
HVAC Supplied	144	49	84	127	92	61	104	94	93
Pavements Required	96	24	24	48	36	24	60	24	24
Pavements Supplied	124	58	75	91	61	86	91	97	57
Structures Required	87	21	24	36	21	24	15	30	21
Structures Supplied	109	71	60	81	72	77	117	95	73
Utilities Required	102	24	30	54	27	39	0	24	24
Utilities Supplied	128	70	71	101	80	76	101	106	73
LiqFuels Required	0	6	6	6	0	0	0	0	6
LiqFuels Supplied	23	12	10	18	19	14	17	20	22
PestMgmt Required	6	6	6	6	6	6	0	6	6
PestMgmt Supplied	16	13	11	14	11	11	13	15	14
EA Required	42	9	24	15	9	15	12	9	9
EA Supplied	63	35	40	71	45	38	44	57	38
OpsMgmt Required	18	6	9	12	6	9	0	6	6
OpsMgmt Supplied	18	11	13	16	16	17	23	19	29

Scenario 8: Objective Function = 0.73072 (Test Model M4)

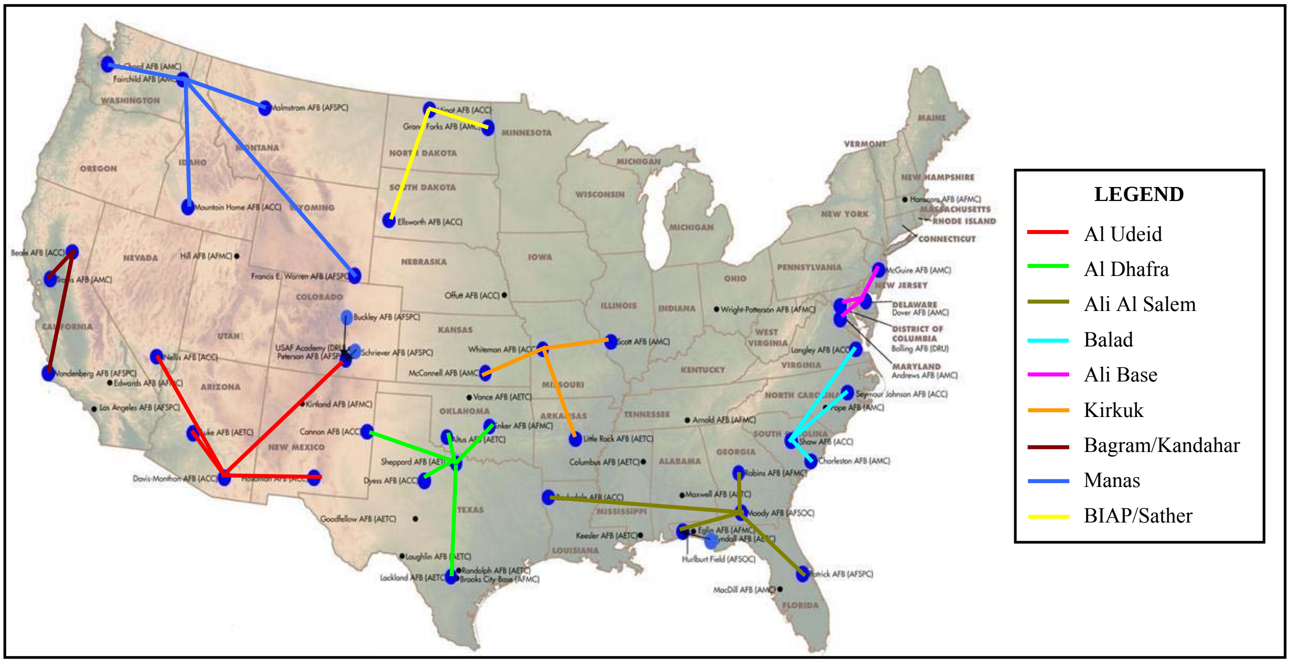


Figure C.8 - Hub-and-Spoke Networks for Scenario 8

Table C.8 – Summary of Scenario 8 Solution

FOB	Al Udeid	Al Dhafra	Ali Al Salem	Balad	Ali Base	Kirkuk	Bagram/Kandahar	Manas	BIAP/Sather
Hub	Davis Monthan	Sheppard	Moody	Shaw	Dover	Whiteman	Beale	Fairchild	Minot
Spokes	Holloman, Luke, Nellis, Peterson (SchrieverBuckley)	Altus, Cannon, Dyess, Lackland, Tinker	Barksdale, HurlburtFld (Tyndall), Patrick, Robins	Charleston, Langley, Seymour Johnson	Andrews, Bolling, McGuire	Little Rock, McConnell, Scott	Travis, Vandenberg	FE Warren, Malmstrom, McChord, Mt Home	Ellsworth, Grand Forks
Total Distance	1712	1090	1502	680	313	829	499	2215	678
Max Distance	825	397	819	369	119	349	407	1014	463
Average Distance	342.4	181.7	300.4	170.0	78.3	207.3	166.3	443.0	226.0
FOB Mission	KC135, KC10, C130, F15	KC10	C130	C130, F16, A10	C130	NA	C130, F15, A10	KC135, C17	C130, C17
H-S Missions	C130(1), F15(1), F16(3), A10(2)	KC135(2), KC10(1), C130(1), C17(1), F16(2)	KC135(1), C130(3), C17(1), F15(2), A10(2)	KC135(1), C17(1), F15(2), F16(2), A10(1)	KC135(1), KC10(1), C17(1), F16(1)	KC135(2), C130(1), A10(1)	KC135(1), KC10(1), C17(1)	KC135(1), C17(1), F15(1), F16(1)	KC135(1)
Airlift Count	1	3	2	2	3	3	2	2	1
Cold Wx H-S Bases	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4	N/A
Officers Required	30	9	21	18	12	18	6	15	12
Officers Supplied	66	35	59	41	46	33	30	40	27
Chiefs Required	3	3	6	3	3	3	0	3	3
Chiefs Supplied	8	5	8	5	7	4	4	5	5
Supert Required	12	9	12	15	15	12	0	12	9
Supert Supplied	39	23	25	27	24	20	23	25	23
FrstSgt Required	3	3	3	3	3	3	0	3	3
FrstSgt Supplied	9	6	6	6	5	4	4	5	5
Supply Required	18	6	6	12	6	6	6	6	6
Supply Supplied	24	11	18	19	21	23	16	14	19
Electric Required	96	30	24	45	24	24	15	21	21
Electric Supplied	123	86	78	76	82	68	93	93	75
PowerPro Required	30	21	48	66	48	12	18	6	36
PowerPro Supplied	131	90	105	91	62	44	80	52	50
HVAC Required	108	27	36	45	27	27	0	27	27
HVAC Supplied	165	96	85	122	68	70	87	79	76
Pavements Required	96	24	24	48	36	24	60	24	24
Pavements Supplied	113	59	65	93	83	61	83	105	78
Structures Required	87	21	24	36	21	24	15	30	21
Structures Supplied	157	66	66	80	83	72	59	92	80
Utilities Required	102	24	30	54	27	39	0	24	24
Utilities Supplied	143	65	77	97	88	80	74	94	88
LiqFuels Required	0	6	6	6	0	0	0	0	6
LiqFuels Supplied	18	21	15	16	14	19	18	17	17
PestMgmt Required	6	6	6	6	6	6	0	6	6
PestMgmt Supplied	23	11	11	17	14	11	5	14	12
EA Required	42	9	24	15	9	15	12	9	9
EA Supplied	67	34	57	48	49	44	37	44	51
OpsMgmt Required	18	6	9	12	6	9	0	6	6
OpsMgmt Supplied	30	27	12	18	14	16	9	20	16

Appendix C

Scenario 9: Objective Function = 0.76290 (Test Model N2)

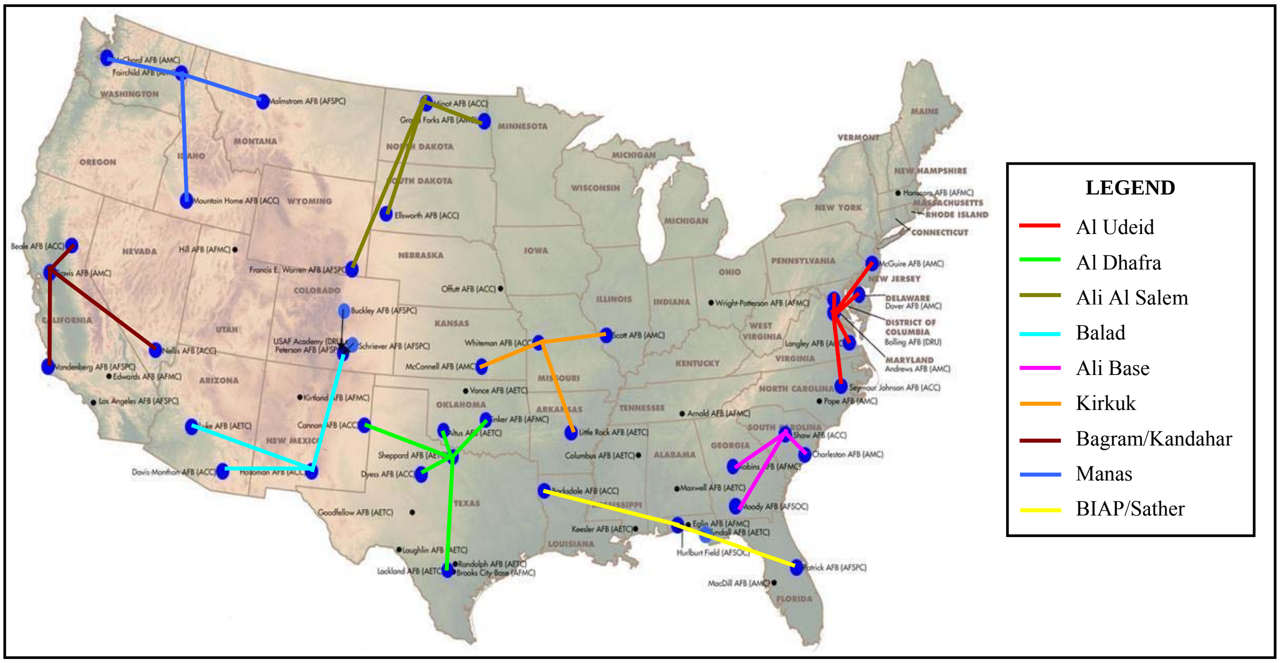


Figure C.9 - Hub-and-Spoke Networks for Scenario 9

Table C.9 – Summary of Scenario 9 Solution

FOB	Al Udeid	Al Dhafra	Ali Al Salem	Balad	Ali Base	Kirkuk	Bagram/Kandahar	Manas	BIAP/Sather
Hub	Andrews	Sheppard	Minot	Holloman	Shaw	Whiteman	Travis	Fairchild	HurlburtFld (Tyndall)
Spokes	Bolling, Dover, Langley, McGuire, Seymour Johnson	Altus, Cannon, Dyess, Lackland, Tinker	Ellsworth, FE Warren, Grand Forks	Davis Monthan, Luke, Peterson (SchrieverBuckley)	Charleston, Moody, Robins	Little Rock, McConnell, Scott	Beale, Nellis, Vandenberg	Malmstrom, McChord, Mt Home	Barksdale, Patrick
Total Distance	742	1090	1388	1290	670	829	1011	1201	975
Max Distance	288	397	710	492	312	349	601	472	492
Average Distance	123.7	181.7	347.0	322.5	167.5	207.3	252.8	300.3	325.0
FOB Mission	KC135, KC10, C130, F15	KC10	C130	C130, F16, A10	C130	NA	C130, F15, A10	KC135, C17	C130, C17
H-S Missions	KC135(2), KC10(1), C17(1), F15(2), F16(2), A10(1)	KC135(2), KC10(1), C130(1), C17(1), F16(2)	KC135(1)	C130(1), F16(2), A10(1)	KC135(1), C130(1), C17(2), F15(1), F16(1), A10(1)	KC135(2), C130(1), A10(1)	KC135(1), KC10(1), C17(1), F15(1), F16(1), A10(1)	KC135(1), C17(1), F15(1), F16(1)	C130(2), F15(1), A10(1)
Airlift Count	4	3	1	1	2	3	2	2	1
Cold Wx H-S Bases	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3	N/A
Officers Required	30	9	21	18	12	18	6	15	12
Officers Supplied	64	35	36	55	33	33	41	31	49
Chiefs Required	3	3	6	3	3	3	0	3	3
Chiefs Supplied	10	5	6	6	3	4	6	4	7
Supert Required	12	9	12	15	15	12	0	12	9
Supert Supplied	39	23	28	30	19	20	32	20	18
FrstSgt Required	3	3	3	3	3	3	0	3	3
FrstSgt Supplied	8	6	6	7	5	4	6	4	4
Supply Required	18	6	6	12	6	6	6	6	6
Supply Supplied	31	11	20	19	15	23	21	13	12
Electric Required	96	30	24	45	24	24	15	21	21
Electric Supplied	122	86	95	97	51	68	119	73	63
PowerPro Required	30	21	48	66	48	12	18	6	36
PowerPro Supplied	107	90	61	107	102	44	104	41	49
HVAC Required	108	27	36	45	27	27	0	27	27
HVAC Supplied	133	96	94	124	90	70	128	61	52
Pavements Required	96	24	24	48	36	24	60	24	24
Pavements Supplied	133	59	97	84	59	61	112	86	49
Structures Required	87	21	24	36	21	24	15	30	21
Structures Supplied	131	66	95	124	45	72	92	77	53
Utilities Required	102	24	30	54	27	39	0	24	24
Utilities Supplied	141	65	106	110	62	80	107	76	59
LiqFuels Required	0	6	6	6	0	0	0	0	6
LiqFuels Supplied	22	21	20	13	11	19	23	14	12
PestMgmt Required	6	6	6	6	6	6	0	6	6
PestMgmt Supplied	24	11	15	16	9	11	12	11	9
EA Required	42	9	24	15	9	15	12	9	9
EA Supplied	75	34	57	48	35	44	56	38	44
OpsMgmt Required	18	6	9	12	6	9	0	6	6
OpsMgmt Supplied	24	27	19	24	13	16	15	17	7

Scenario 10: Objective Function = 0.76429 (Test Model N1)

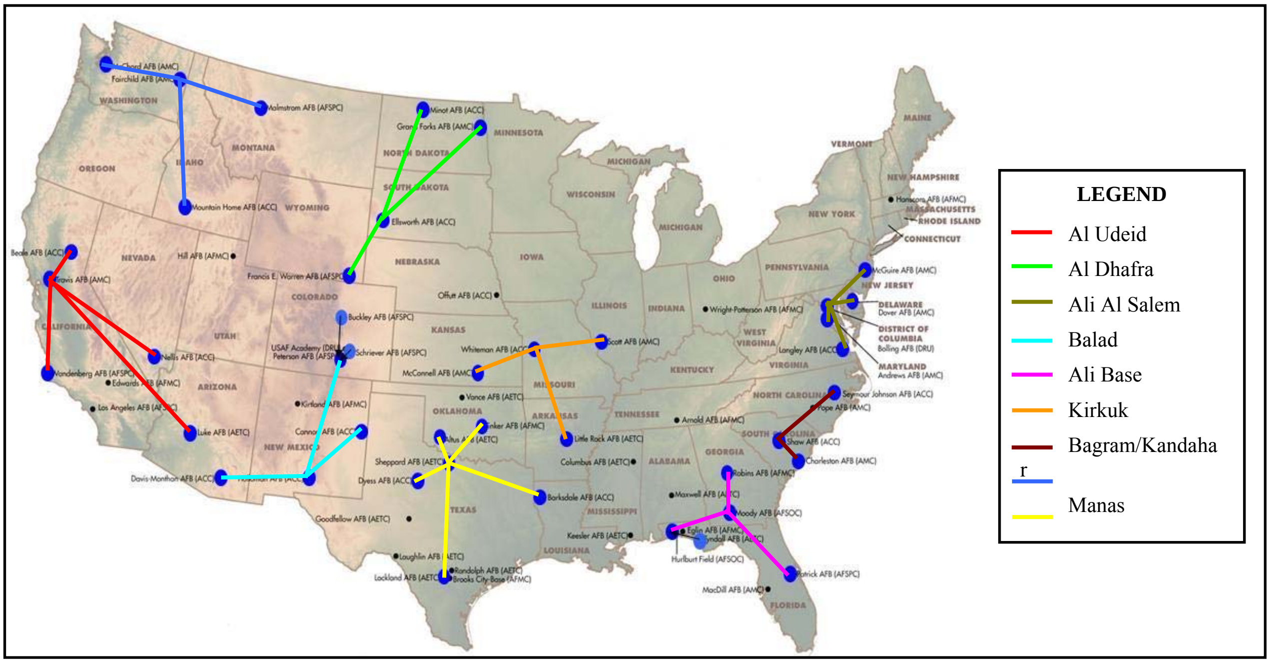


Figure C.10 - Hub-and-Spoke Networks for Scenario 10

Table C.10 – Summary of Scenario 10 Solution

FOB	Al Udeid	Al Dhafra	Ali Al Salem	Balad	Ali Base	Kirkuk	Bagram/Kandahar	Manas	BIAP/Sather
Hub	Travis	Ellsworth	Bolling	Holloman	Moody	Whiteman	Shaw	Fairchild	Sheppard
Spokes	Beale, Luke, Nellis, Vandenberg	FE Warren, Grand Forks, Minot	Andrews, Dover, Langley, McGuire	Cannon, Davis Monthan, Peterson (SchrieverBuckley)	HurlburtFld (Tyndall), Patrick, Robins	Little Rock, McConnell, Scott	Charleston, Seymour Johnson	Malmstrom, McChord, Mt Home	Altus, Barksdale, Dyess, Lackland, Tinker
Total Distance	1768	1444	462	1055	683	829	311	1201	1133
Max Distance	757	651	176	492	287	349	206	472	397
Average Distance	353.6	361.0	92.4	263.8	170.8	207.3	103.7	300.3	188.8
FOB Mission	KC135, KC10, C130, F15	KC10	C130	C130, F16, A10	C130	NA	C130, F15, A10	KC135, C17	C130, C17
H-S Missions	KC135(1), KC10(1), C17(1), F15(1), F16(2), A10(1)	KC135(1)	KC135(1), KC10(1), C17(1), F15(1), F16(2), A10(1)	C130(1), F16(2), A10(1)	KC135(1), C130(3), C17(1), F15(2), A10(1)	KC135(2), C130(1), A10(1)	KC135(1), C17(1), F15(1), F16(1)	KC135(1), C17(1), F15(1), F16(1)	KC135(2), KC10(1), C130(1), C17(1), F16(1), A10(1)
Airlift Count	2	1	3	1	2	3	2	2	3
Cold Wx H-S Bases	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3	N/A
Officers Required	30	9	21	18	12	18	6	15	12
Officers Supplied	47	36	56	59	49	33	31	31	35
Chiefs Required	3	3	6	3	3	3	0	3	3
Chiefs Supplied	7	6	9	6	7	4	3	4	5
Supert Required	12	9	12	15	15	12	0	12	9
Supert Supplied	36	28	33	31	20	20	18	20	23
FrstSgt Required	3	3	3	3	3	3	0	3	3
FrstSgt Supplied	7	6	7	7	5	4	4	4	6
Supply Required	18	6	6	12	6	6	6	6	6
Supply Supplied	27	20	27	16	12	23	13	13	14
Electric Required	96	30	24	45	24	24	15	21	21
Electric Supplied	131	95	104	99	62	68	54	73	88
PowerPro Required	30	21	48	66	48	12	18	6	36
PowerPro Supplied	116	61	92	110	93	44	61	41	87
HVAC Required	108	27	36	45	27	27	0	27	27
HVAC Supplied	144	94	116	121	70	70	74	61	98
Pavements Required	96	24	24	48	36	24	60	24	24
Pavements Supplied	124	97	110	91	48	61	66	86	57
Structures Required	87	21	24	36	21	24	15	30	21
Structures Supplied	109	95	108	124	49	72	55	77	66
Utilities Required	102	24	30	54	27	39	0	24	24
Utilities Supplied	128	106	116	110	57	80	69	76	64
LiqFuels Required	0	6	6	6	0	0	0	0	6
LiqFuels Supplied	23	20	18	17	10	19	12	14	22
PestMgmt Required	6	6	6	6	6	6	0	6	6
PestMgmt Supplied	16	15	18	15	7	11	13	11	12
EA Required	42	9	24	15	9	15	12	9	9
EA Supplied	63	57	62	48	49	44	35	38	35
OpsMgmt Required	18	6	9	12	6	9	0	6	6
OpsMgmt Supplied	18	19	19	26	8	16	13	17	26

Appendix D

Model Screen Shots

Main Tab

	A	B	C	D	E	F	G
1							
2	Tabs	Tab Type	Description			Cell Color Key	Adjustable by User?
3	Main	Summary	Provides a summary of all tabs and legends for color coding			Obj Function Cells	No
4	Optimization Tab	Optimization	Constains a necessary solver cells for the model's optimization problem			Decision Variable	No
5	Objective Funct Calc	Optimization	Shows earned values and weights used to calculate of the objective function			Constraint Cell	No
6	Optimization Summary	Optimization	Summarizes the resulting scenario			Calculated Cell	No
7	Distance Calc	Calculation	Calculates distances given DV values and distance table data			Info Only	No
8	Personnel Calc	Calculation	Calculates personnel overages when comparing Hub supply and FOB demand			Adjustable Data	Yes
9	Airlift Calc	Calculation	Calculates the number of airlift capable units within each network				
10	Cold Wx Calc	Calculation	Calculates the number of cold weather bases assigned to cold weather FOBs			Note: Red and Yellow Cells, seen on the Optimization Tab under the Personnel and Mission Matching Objective calculations, are a result of conditional formatting that is used to identify potential concerns.	
11	Mission Calc	Calculation	Calculates the number of missions matched between bases and supported FOBs				
12	Base Info	Data	Contains information on all home station bases in the model including: personnel (by career field), mission, & cold weather coding.				
13	FOB Rqmts	Data	Contains requirements for all FOBs in the model including: personnel (by career field), & mission.				
14	Distance Table	Data	Table of distances between all home station bases in the model				
15	Map	Figure	CONUS map of major AF installations w/ 50+ and 100+ personnel				

Figure D.1 – Screenshot of Main Tab

Optimization Tab

0.72754838

Spoke-Hub Matrix

Row	Spoke / Hub	Davis Monthan	Dover	Dyess	Ellsworth	Fairchild	FE Warren	Grand Forks	Holloman	HurlburtFld (Tyndall)	Lackland	Langley	Little Rock	Luke	Malmstrom	McChord	McConnell	McGuire	Minot	Moody	Mt Home	Nellis	Patrick	Peterson (Schriever	Robins	Scott	Seymour Johnson	Shaw	Sheppard	Tinker	Travis	Vandenberg	Whiteman	Assignment Totals		
5	Altus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1		
6	Andrews	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
7	Barksdale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
8	Beale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
9	Bolling	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
10	Cannon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1		
11	Charleston	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1		
12	Davis Monthan	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
13	Dover	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
14	Dyess	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1		
15	Ellsworth	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
16	Fairchild	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
17	FE Warren	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
18	Grand Forks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
19	Holloman	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
20	HurlburtFld (Tyndall)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
21	Lackland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1		
22	Langley	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1		
23	Little Rock	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1		
24	Luke	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
25	Malmstrom	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
26	McChord	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
27	McConnell	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1		
28	McGuire	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
29	Minot	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
30	Moody	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
31	Mt Home	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
32	Nellis	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
33	Patrick	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
34	Peterson (SchrieverBuckley)	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
35	Robins	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
36	Scott	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1		
37	Seymour Johnson	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1		
38	Shaw	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1		
39	Sheppard	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1		
40	Tinker	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1		
41	Travis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
42	Vandenberg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
43	Whiteman	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1		
44	Totals	5	4	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	3	5	0	0	0	0	0	0	0	4	6	0	0	0	4			
45	Linking Constraint	-55	-56	0	0	-55	0	0	0	0	0	0	0	0	0	0	0	0	-57	-55	0	0	0	0	0	0	0	-56	-54	0	0	0	-56		# Hubs	# FOBs
46	A Hub? Binary	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1	0	0	0	1		9	9

Hub-FOB Matrix

Row	FOB / Hub	Davis Monthan	Dover	Dyess	Ellsworth	Fairchild	FE Warren	Grand Forks	Holloman	HurlburtFld (Tyndall)	Lackland	Langley	Little Rock	Luke	Malmstrom	McChord	McConnell	McGuire	Minot	Moody	Mt Home	Nellis	Patrick	Peterson (SchrieverBuckley)	Robins	Scott	Seymour Johnson	Shaw	Sheppard	Tinker	Travis	Vandenberg	Whiteman	Group Totals
50	Al Udeid	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
51	Al Dhafra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
52	Ali Al Salem	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
53	Balad	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
54	Ali Base	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
55	Kirkuk	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
56	Bagram/Kandahar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
57	Manas	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
58	BIAP/Sather	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
60	Hub Totals 2	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1	0	0	0	1	9
61	Hub Totals 1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1	0	0	0	1	9

Figure D.2 – Screenshot of Optimization Tab (Top Half)

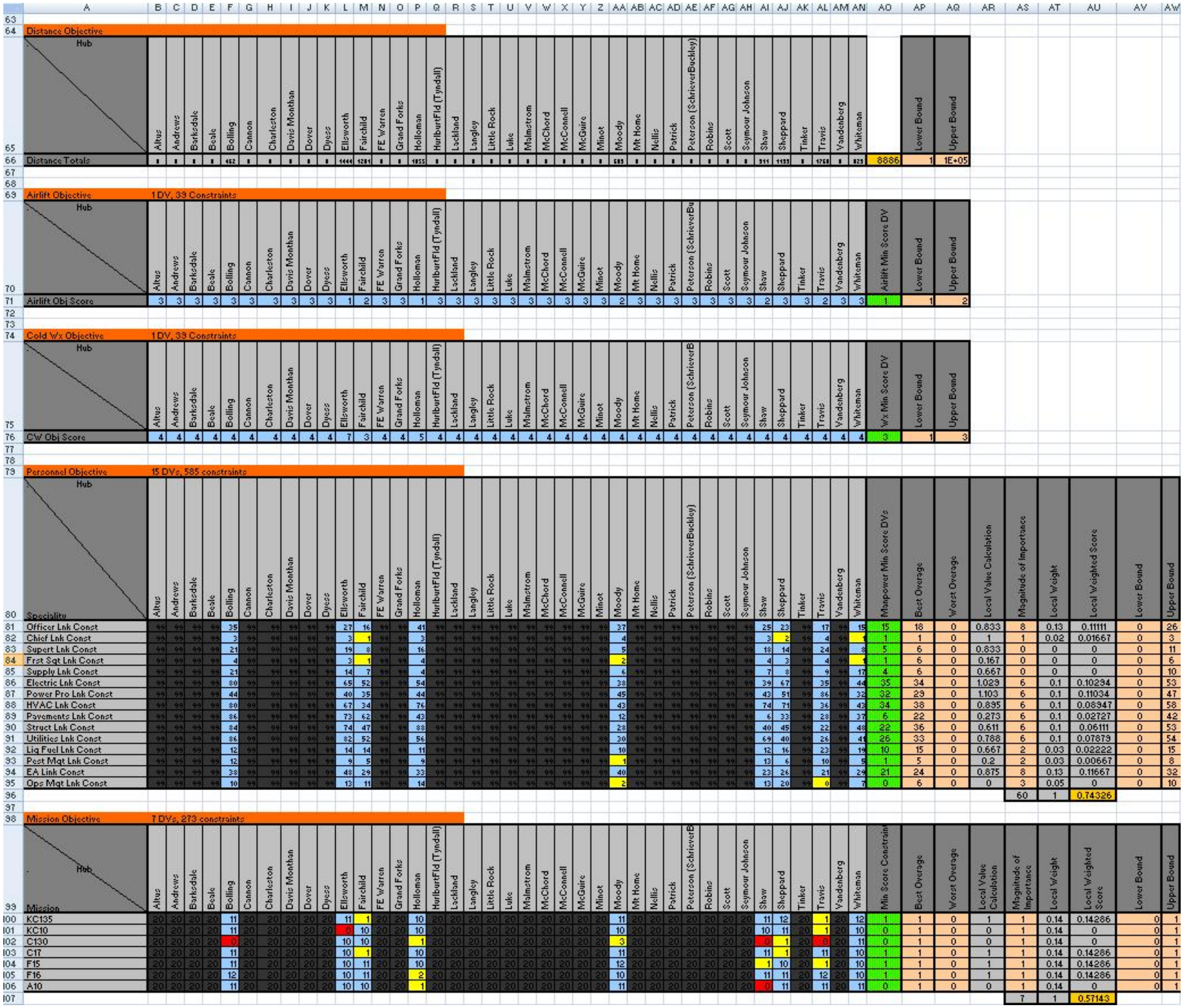


Figure D.3 - Screenshot of Optimization Tab (Lower Half)

Appendix D

Objective Function Calculation Tab

	A	B	C	D	E	F	G
1	Objective	Objective Score	Objective Value	Magnitude of Importance	Weight of Objective	Weighted Value	
2	Manning	0.743265	0.743265	2	0.1333333	0.099	
3	Distance	8886	0.791	10	0.6666667	0.527	
4	Airlift	1	0.5	1	0.0666667	0.033	
5	Weather	3	1	1	0.0666667	0.067	
6	Mission	0.571429	0.571429	1	0.0666667	0.038	
7	TOTALS	NA	NA	15	1	0.7643	Maximize
8							
9							
10	Distance SDVF Factors						
11	Best Score	5458					
12	Worst Score	21832					
13							
14	Airlift SDVF Factors						
15	Best Score	2					
16	Worst Score	0					
17							
18	Weather SDVF Factors						
19	Best Score	3					
20	Worst Score	0					

Figure D.4 – Screenshot of Objective Function Calculation Tab

Distance Calc Tab

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO
1	Hub \ Spoke	Altus	Andrews	Barksdale	Beale	Bolling	Cannon	Charleston	Davis Monthan	Dover	Dyess	Ellsworth	Fairchild	FE Warren	Grand Forks	Holloman	HurlburtFld (Tyndall)	Lackland	Langley	Little Rock	Luke	Malmstrom	McChord	McConnell	McGuire	Minot	Moody	Mt Home	Nellis	Patrick	Peterson (SchrieverBuckley)	Robins	Scott	Seymour Johnson	Shaw	Sheppard	Tinker	Travis	Vandenberg	Whiteman	
2	Altus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	88	0	0	0	0	
3	Andrews	0	0	0	0	0	0	0	0	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	Barksdale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	819	0	0	0	0	0	0	0	0	0	0	0	0	0	
5	Beale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6	Bolling	0	0	0	0	0	0	0	0	99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
7	Cannon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	297	0	0	0	0	
8	Charleston	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	105	0	0	0	0	0	
9	Davis Monthan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
10	Dover	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
11	Dyess	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	163	0	0	0	0	
12	Ellsworth	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	463	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
13	Fairchild	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
14	FE Warren	0	0	0	0	0	0	0	0	0	0	0	1014	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
15	Grand Forks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	215	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
16	Holloman	0	0	0	0	0	0	0	329	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
17	HurlburtFld (Tyndall)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	254	0	0	0	0	0	0	0	0	0	0	0	0	0	
18	Lackland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	397	0	0	0	0	
19	Langley	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	369	0	0	0	0	0	
20	Little Rock	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	349	
21	Luke	0	0	0	0	0	0	0	141	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	Malmstrom	0	0	0	0	0	0	0	0	0	0	0	418	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23	McChord	0	0	0	0	0	0	0	0	0	0	0	311	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
24	McConnell	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	250	
25	McGuire	0	0	0	0	0	0	0	0	119	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
26	Minot	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
27	Moody	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
28	Mt Home	0	0	0	0	0	0	0	0	0	0	0	472	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
29	Nellis	0	0	0	0	0	0	0	417	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
30	Patrick	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	287	0	0	0	0	0	0	0	0	0	0	0	0	0	
31	Peterson (SchrieverBuckley)	0	0	0	0	0	0	0	825	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
32	Robins	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	142	0	0	0	0	0	0	0	0	0	0	0	0	0	
33	Scott	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	230	
34	Seymour Johnson	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	206	0	0	0	0	0	
35	Shaw	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
36	Sheppard	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
37	Tinker	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	145	0	0	0	0	
38	Travis	0	0	0	92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
39	Vandenberg	0	0	0	407	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
40	Whiteman	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
41	Distance Totals	0	0	0	499	0	0	0	1712	313	0	0	##	0	0	0	0	0	0	0	0	0	0	0	0	678	##	0	0	0	0	0	0	0	680	1090	0	0	0	829	9518

Figure D.5 – Screenshot of Distance Calc Tab

Manpower Calc Tab

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO
1	Calculation																																								
2	Hub Speciality	Altus	Andrews	Barksdale	Beale	Bolling	Cannon	Charleston	Davis Monthan	Dover	Dyess	Ellsworth	Fairchild	FE Warren	Grand Forks	Holloman	HurlburtFld (Tyndall)	Lackland	Langley	Little Rock	Luke	Malmstrom	McChord	McConnell	McGuire	Minot	Moody	Mt Home	Nellis	Patrick	Peterson (Schriever/Buckley)	Robins	Scott	Seymour Johnson	Shaw	Sheppard	Tinker	Travis	Vandenberg	Whiteman	TOTALS
3	Officers	0	0	0	30	0	0	0	66	46	0	0	40	0	0	0	0	0	0	0	0	0	0	0	0	27	59	0	0	0	0	0	0	0	41	35	0	0	0	33	377
4	Chief	0	0	0	4	0	0	0	8	7	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	5	8	0	0	0	0	0	0	0	5	5	0	0	0	4	51
5	Superintendent	0	0	0	23	0	0	0	39	24	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	23	25	0	0	0	0	0	0	0	27	23	0	0	0	20	229
6	First Sergeant	0	0	0	4	0	0	0	9	5	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	5	6	0	0	0	0	0	0	0	6	6	0	0	0	4	50
7	Supply	0	0	0	16	0	0	0	24	21	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	19	18	0	0	0	0	0	0	0	19	11	0	0	0	23	165
8	Electrical	0	0	0	93	0	0	0	123	82	0	0	93	0	0	0	0	0	0	0	0	0	0	0	0	75	78	0	0	0	0	0	0	0	76	86	0	0	0	68	774
9	Power Pro	0	0	0	80	0	0	0	131	62	0	0	52	0	0	0	0	0	0	0	0	0	0	0	0	50	105	0	0	0	0	0	0	0	91	90	0	0	0	44	705
10	HVAC/R	0	0	0	87	0	0	0	165	68	0	0	79	0	0	0	0	0	0	0	0	0	0	0	0	76	85	0	0	0	0	0	0	0	122	96	0	0	0	70	848
11	Pavements	0	0	0	83	0	0	0	113	83	0	0	105	0	0	0	0	0	0	0	0	0	0	0	0	78	65	0	0	0	0	0	0	0	93	59	0	0	0	61	740
12	Structural	0	0	0	59	0	0	0	157	83	0	0	92	0	0	0	0	0	0	0	0	0	0	0	0	80	66	0	0	0	0	0	0	0	80	66	0	0	0	72	755
13	Utilities	0	0	0	74	0	0	0	143	88	0	0	94	0	0	0	0	0	0	0	0	0	0	0	0	88	77	0	0	0	0	0	0	0	97	65	0	0	0	80	806
14	Liquid Fuels	0	0	0	18	0	0	0	18	14	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	17	15	0	0	0	0	0	0	0	16	21	0	0	0	19	155
15	Pest Mgt	0	0	0	5	0	0	0	23	14	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	12	11	0	0	0	0	0	0	0	17	11	0	0	0	11	118
16	Engineering	0	0	0	37	0	0	0	67	49	0	0	44	0	0	0	0	0	0	0	0	0	0	0	0	51	57	0	0	0	0	0	0	0	48	34	0	0	0	44	431
17	Operations Mgt	0	0	0	9	0	0	0	30	14	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	16	12	0	0	0	0	0	0	0	18	27	0	0	0	16	162
18	TOTALS	0	0	0	622	0	0	0	1116	660	0	0	699	0	0	0	0	0	0	0	0	0	0	0	0	622	687	0	0	0	0	0	0	0	756	635	0	0	0	569	6366
21	Null Factor	-99																																							
22																																									
24	Officers																																								
25	Hub Totals	0	0	0	30	0	0	0	66	46	0	0	40	0	0	0	0	0	0	0	0	0	0	0	0	27	59	0	0	0	0	0	0	0	41	35	0	0	0	33	377
26	FOB Rqmt	0	0	0	6	0	0	0	30	12	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	12	21	0	0	0	0	0	0	0	18	9	0	0	0	18	141
27	Null Factor Mask	99	99	99	0	99	99	99	0	0	99	99	0	99	99	99	99	99	99	99	99	99	99	99	99	0	0	99	99	99	99	99	99	99	0	0	99	99	99	0	
28	Officer Lnk Const	99	99	99	24	99	99	99	36	34	99	99	25	99	99	99	99	99	99	99	99	99	99	99	99	15	38	99	99	99	99	99	99	99	23	26	99	99	99	15	236
29																																									
30	Chief																																								
31	Hub Totals	0	0	0	4	0	0	0	8	7	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	5	8	0	0	0	0	0	0	0	5	5	0	0	0	4	51
32	FOB Rqmt	0	0	0	0	0	0	0	3	3	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	3	6	0	0	0	0	0	0	0	3	3	0	0	0	3	27
33	Null Factor Mask	99	99	99	0	99	99	99	0	0	99	99	0	99	99	99	99	99	99	99	99	99	99	99	99	0	0	99	99	99	99	99	99	99	0	0	99	99	99	0	
34	Chief Lnk Const	99	99	99	4	99	99	99	5	4	99	99	2	99	99	99	99	99	99	99	99	99	99	99	99	2	2	99	99	99	99	99	99	99	2	2	99	99	99	1	24
35																																									
36	Superintendent																																								
37	Hub Totals	0	0	0	23	0	0	0	39	24	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	23	25	0	0	0	0	0	0	0	27	23	0	0	0	20	229
38	FOB Rqmt	0	0	0	0	0	0	0	12	15	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	9	12	0	0	0	0	0	0	0	15	9	0	0	0	12	96
39	Null Factor Mask	99	99	99	0	99	99	99	0	0	99	99	0	99	99	99	99	99	99	99	99	99	99	99	99	0	0	99	99	99	99	99	99	99	0	0	99	99	99	0	
40	Supert Lnk Const	99	99	99	23	99	99	99	27	9	99	99	13	99	99	99	99	99	99	99	99	99	99	99	99	14	13	99	99	99	99	99	99	99	12	14	99	99	99	8	133
41																																									
42	First Sergeant																																								
43	Hub Totals	0	0	0	4	0	0	0	9	5	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	5	6	0	0	0	0	0	0	0	6	6	0	0	0	4	50
44	FOB Rqmt	0	0	0	0	0	0	0	3	3	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0	3	3	0	0	0	3	24
45	Null Factor Mask	99	99	99	0	99	99	99	0	0	99	99	0	99	99	99	99	99	99	99	99	99	99	99	99	0	0	99	99	99	99	99	99	99	0	0	99	99	99	0	
46	Frst Sgt Lnk Const	99	99	99	4	99	99	99	6	2	99	99	2	99	99	99	99	99	99	99	99	99	99	99	99	2	3	99	99	99	99	99	99	99	3	3	99	99	99	1	26
47																																									
48	Supply																																								
49	Hub Totals	0	0	0	16	0	0	0	24	21	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	19	18	0	0	0	0	0	0	0	19	11	0	0	0	23	165
50	FOB Rqmt	0	0	0	6	0	0	0	18	6	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	6	6	0	0	0	0	0	0	0	12	6	0	0	0	6	72
51	Null Factor Mask	99	99	99	0	99	99	99	0	0	99	99	0	99	99	99	99	99	99	99	99	99	99	99	99	0	0	99	99	99	99	99	99	99	0	0	99	99	99	0	
52	Supply Lnk Const	99	99	99	10	99	99	99	6	15	99	99	8	99	99	99	99	99	99	99	99	99	99	99	99	13	12	99	99	99	99	99	99	99	7	5	99	99	99	17	93
53																																									
54	Electrical																																								
55	Hub Totals	0	0	0	93	0	0	0	123	82	0	0	93	0	0	0	0	0	0	0	0	0	0	0	0	75	78	0	0	0	0	0	0	0	76	86	0	0	0	68	774
56	FOB Rqmt	0	0	0	15	0	0	0	96	24	0	0	21	0	0	0	0	0	0	0	0	0	0	0	0	21	24	0	0	0	0	0	0	0	45	30	0	0	0	24	300
57	Null Factor Mask	99	99	99	0	99	99	99	0	0	99	99	0	99	99	99	99	99	99	99	99	99	99	99	99	0	0	99	99	99	99	99	99	99	0	0	99	99	99	0	
58	Electric Lnk Const	99	99	99	78	99	99	99	27	58	99	99	72	99	99	99	99	99	99	99	99	99	99	99	99	54	54	99	99	99	99	99	99	99	31	56	99	99	99	44	474
59																																									
60	Power Pro																																								
61	Hub Totals	0	0	0	80	0	0	0	131	62	0	0	52	0	0	0	0	0	0	0	0	0	0	0	0	50	105	0	0	0	0	0	0	0	91	90	0	0	0	44	705
62	FOB Rqmt	0	0	0	18	0	0	0	30	48	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	36	48	0	0	0	0	0	0	0	66	21	0	0	0	12	285
63	Null Factor Mask	99	99	99	0	99	99	99	0	0	99	99	0	99	99	99	99	99	99	99	99	99	99	99	99	0	0	99	99	99	99	99	99	99	0	0	99	99	99	0	
64	Power Pro Lnk Const	99	99	99	62	99	99	99	101	14	99	99	46	99	99	99	99	99	99	99	99	99	99	99	99	14	57	99	99	99	99	99	99	99	25	69	99	99	99	32	420
65																																									
66	HVAC/R																																								
67	Hub Totals	0	0	0	87	0	0	0	165	68	0	0	79	0	0	0	0	0	0	0	0	0	0	0	0	76	85	0	0	0	0	0	0	0	122	96	0	0	0	70	848
68	FOB Rqmt	0	0	0	0	0	0	0	108	27	0	0	27	0	0	0	0	0	0	0	0	0	0	0	0	27	36	0	0	0	0	0	0	0	45	27	0	0	0	27	324
69	Null Factor Mask	99	99	99	0	99	99	99	0	0	99	99	0	99	99	99	99	99	99	99	99	99	99	99	99	0	0	99	99	99	99	99	99	99	0	0	99	99	99	0	
70	HVAC Lnk Const	99	99	99	87	99	99	99	57	41	99	99	52	99	99	99	99	99	99	99	99	99	99	99	99	49	49	99	99	99	99	99	99	99	77	69	99	99	99	43	524

Figure D.6 – Screenshot of Manpower Calc Tab (Top Third)

2	Speciality	Altus	Andrews	Barksdale	Beale	Bolling	Cannon	Charleston	Davis Monthan	Dover	Dyess	Ellsworth	Fairchild	FE Warren	Grand Forks	Holloman
72	Pavements															
73	Hub Totals	0	0	0	83	0	0	0	113	83	0	0	105	0	0	0
74	FOB Rqmt	0	0	0	60	0	0	0	96	36	0	0	24	0	0	0
75	Null Factor Mask	99	99	99	0	99	99	99	0	0	99	99	0	99	99	99
76	Pavements Lnk Const	99	99	99	23	99	99	99	17	47	99	99	81	99	99	99
77																
78	Structural															
79	Hub Totals	0	0	0	59	0	0	0	157	83	0	0	92	0	0	0
80	FOB Rqmt	0	0	0	15	0	0	0	87	21	0	0	30	0	0	0
81	Null Factor Mask	99	99	99	0	99	99	99	0	0	99	99	0	99	99	99
82	Struct Lnk Const	99	99	99	44	99	99	99	70	62	99	99	62	99	99	99
83																
84	Utilities															
85	Hub Totals	0	0	0	74	0	0	0	143	88	0	0	94	0	0	0
86	FOB Rqmt	0	0	0	0	0	0	0	102	27	0	0	24	0	0	0
87	Null Factor Mask	99	99	99	0	99	99	99	0	0	99	99	0	99	99	99
88	Utilities Lnk Const	99	99	99	74	99	99	99	41	61	99	99	70	99	99	99
89																
90	Liquid Fuels															
91	Hub Totals	0	0	0	18	0	0	0	18	14	0	0	17	0	0	0
92	FOB Rqmt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
93	Null Factor Mask	99	99	99	0	99	99	99	0	0	99	99	0	99	99	99
94	Liq Fuel Lnk Const	99	99	99	18	99	99	99	18	14	99	99	17	99	99	99
95																
96	Pest Mgt															
97	Hub Totals	0	0	0	5	0	0	0	23	14	0	0	14	0	0	0
98	FOB Rqmt	0	0	0	0	0	0	0	6	6	0	0	6	0	0	0
99	Null Factor Mask	99	99	99	0	99	99	99	0	0	99	99	0	99	99	99
100	Pest Mgt Lnk Const	99	99	99	5	99	99	99	17	8	99	99	8	99	99	99
101																
102	Engineering															
103	Hub Totals	0	0	0	37	0	0	0	67	49	0	0	44	0	0	0
104	FOB Rqmt	0	0	0	12	0	0	0	42	9	0	0	9	0	0	0
105	Null Factor Mask	99	99	99	0	99	99	99	0	0	99	99	0	99	99	99
106	EA Link Const	99	99	99	25	99	99	99	25	40	99	99	35	99	99	99
107																
108	Operations Mgt															
109	Hub Totals	0	0	0	9	0	0	0	30	14	0	0	20	0	0	0
110	FOB Rqmt	0	0	0	0	0	0	0	18	6	0	0	6	0	0	0
111	Null Factor Mask	99	99	99	0	99	99	99	0	0	99	99	0	99	99	99
112	Ops Mgt Lnk Const	99	99	99	9	99	99	99	12	8	99	99	14	99	99	99

2	Speciality	HurlburtFld (Tynda	Lackland	Langley	Little Rock	Luke	Malmstrom	McChord	McConnell	McGuire
72	Pavements									
73	Hub Totals	0	0	0	0	0	0	0	0	0
74	FOB Rqmt	0	0	0	0	0	0	0	0	0
75	Null Factor Mask	99	99	99	99	99	99	99	99	99
76	Pavements Lnk Const	99	99	99	99	99	99	99	99	99
77										
78	Structural									
79	Hub Totals	0	0	0	0	0	0	0	0	0
80	FOB Rqmt	0	0	0	0	0	0	0	0	0
81	Null Factor Mask	99	99	99	99	99	99	99	99	99
82	Struct Lnk Const	99	99	99	99	99	99	99	99	99
83										
84	Utilities									
85	Hub Totals	0	0	0	0	0	0	0	0	0
86	FOB Rqmt	0	0	0	0	0	0	0	0	0
87	Null Factor Mask	99	99	99	99	99	99	99	99	99
88	Utilities Lnk Const	99	99	99	99	99	99	99	99	99
89										
90	Liquid Fuels									
91	Hub Totals	0	0	0	0	0	0	0	0	0
92	FOB Rqmt	0	0	0	0	0	0	0	0	0
93	Null Factor Mask	99	99	99	99	99	99	99	99	99
94	Liq Fuel Lnk Const	99	99	99	99	99	99	99	99	99
95										
96	Pest Mgt									
97	Hub Totals	0	0	0	0	0	0	0	0	0
98	FOB Rqmt	0	0	0	0	0	0	0	0	0
99	Null Factor Mask	99	99	99	99	99	99	99	99	99
100	Pest Mgt Lnk Const	99	99	99	99	99	99	99	99	99
101										
102	Engineering									
103	Hub Totals	0	0	0	0	0	0	0	0	0
104	FOB Rqmt	0	0	0	0	0	0	0	0	0
105	Null Factor Mask	99	99	99	99	99	99	99	99	99
106	EA Link Const	99	99	99	99	99	99	99	99	99
107										
108	Operations Mgt									
109	Hub Totals	0	0	0	0	0	0	0	0	0
110	FOB Rqmt	0	0	0	0	0	0	0	0	0
111	Null Factor Mask	99	99	99	99	99	99	99	99	99
112	Ops Mgt Lnk Const	99	99	99	99	99	99	99	99	99

2	Speciality	Minot	Moody	Mt Home	Nellis	Patrick	Peterson (Schriev	Robins	Scott	Seymour Johnson	Shaw	Sheppard	Tinker	Travis	Vandenberg	Whiteman	TOTALS
72	Pavements																
73	Hub Totals	78	65	0	0	0	0	0	0	0	93	59	0	0	0	61	740
74	FOB Rqmt	24	24	0	0	0	0	0	0	0	48	24	0	0	0	24	360
75	Null Factor Mask	0	0	99	99	99	99	99	99	99	0	0	99	99	99	0	
76	Pavements Lnk Const	54	41	99	99	99	99	99	99	99	45	35	99	99	99	37	380
77																	
78	Structural																
79	Hub Totals	80	66	0	0	0	0	0	0	0	80	66	0	0	0	72	755
80	FOB Rqmt	21	24	0	0	0	0	0	0	0	36	21	0	0	0	24	279
81	Null Factor Mask	0	0	99	99	99	99	99	99	99	0	0	99	99	99	0	
82	Struct Lnk Const	59	42	99	99	99	99	99	99	99	44	45	99	99	99	48	476
83																	
84	Utilities																
85	Hub Totals	88	77	0	0	0	0	0	0	0	97	65	0	0	0	80	806
86	FOB Rqmt	24	30	0	0	0	0	0	0	0	54	24	0	0	0	39	324
87	Null Factor Mask	0	0	99	99	99	99	99	99	99	0	0	99	99	99	0	
88	Utilities Lnk Const	64	47	99	99	99	99	99	99	99	43	41	99	99	99	41	482
89																	
90	Liquid Fuels																
91	Hub Totals	17	15	0	0	0	0	0	0	0	16	21	0	0	0	19	155
92	FOB Rqmt	6	6	0	0	0	0	0	0	0	6	6	0	0	0	0	24
93	Null Factor Mask	0	0	99	99	99	99	99	99	99	0	0	99	99	99	0	
94	Liq Fuel Lnk Const	11	9	99	99	99	99	99	99	99	10	15	99	99	99	19	131
95																	
96	Pest Mgt																
97	Hub Totals	12	11	0	0	0	0	0	0	0	17	11	0	0	0	11	118
98	FOB Rqmt	6	6	0	0	0	0	0	0	0	6	6	0	0	0	6	48
99	Null Factor Mask	0	0	99	99	99	99	99	99	99	0	0	99	99	99	0	
100	Pest Mgt Lnk Const	6	5	99	99	99	99	99	99	99	11	5	99	99	99	5	70
101																	
102	Engineering																
103	Hub Totals	51	57	0	0	0	0	0	0	0	48	34	0	0	0	44	431
104	FOB Rqmt	9	24	0	0	0	0	0	0	0	15	9	0	0	0	15	144
105	Null Factor Mask	0	0	99	99	99	99	99	99	99	0	0	99	99	99	0	
106	EA Link Const	42	33	99	99	99	99	99	99	99	33	25	99	99	99	29	287
107																	
108	Operations Mgt																
109	Hub Totals	16	12	0	0	0	0	0	0	0	18	27	0	0	0	16	162
110	FOB Rqmt	6	9	0	0	0	0	0	0	0	12	6	0	0	0	9	72
111	Null Factor Mask	0	0	99	99	99	99	99	99	99	0	0	99	99	99	0	
112	Ops Mgt Lnk Const	10	3	99	99	99	99	99	99	99	6	21	99	99	99	7	90

Figure D.7 – Screenshot of Manpower Calc Tab (Middle Third)

217	FOB Rqmts tab Data Extrapolation																
218	Speciality / FOB	Officers	Chief	Superintendent	First Sergeant	Supply	Electrical	Power Pro	HVAC/R	Pavements	Structural	Utilities	Liquid Fuels	Pest Mgt	Engineering	Operations Mgt	Cycle Total
219	Al Udeid	30	3	12	3	18	96	30	108	96	87	102	0	6	42	18	651
220	Al Dhafra	9	3	9	3	6	30	21	27	24	21	24	6	6	9	6	204
221	Ali Al Salem	21	6	12	3	6	24	48	36	24	24	30	6	6	24	9	279
222	Balad	18	3	15	3	12	45	66	45	48	36	54	6	6	15	12	384
223	Ali Base	12	3	15	3	6	24	48	27	36	21	27	0	6	9	6	243
224	Kirkuk	18	3	12	3	6	24	12	27	24	24	39	0	6	15	9	222
225	Bagram/Kandahar	6	0	0	0	6	15	18	0	60	15	0	0	0	12	0	132
226	Manas	15	3	12	3	6	21	6	27	24	30	24	0	6	9	6	192
227	BIAP/Sather	12	3	9	3	6	21	36	27	24	21	24	6	6	9	6	213
228	EMPTY FOB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
229	Cycle Total (+ overage)	141	27	96	24	72	300	285	324	360	279	324	24	48	144	72	2520
230																	
231	Number of Buckets	3															
232	100% Factor	1.00															
233	Overage Factor	0.00															
234	Total Multiplier	1.00															
235	Requirement Formula: (Per bucket requirement x Number of Buckets) x Total Multiplier																

Figure D.8 – Screenshot of Manpower Calc Tab (Lower Third)

Airlift Calc Tab

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	Calculation																			
2		Altus	Andrews	Barksdale	Beale	Bolling	Cannon	Charleston	Davis Monthan	Dover	Dyess	Ellsworth	Fairchild	FE Warren	Grand Forks	Holloman	HurlburtFld (Tyndall)	Lackland	Langley	Little Rock
3	Hub Airlift Totals	0	0	0	2	0	0	0	1	3	0	0	2	0	0	0	0	0	0	0
4	Hubs?	3	3	3	0	3	3	3	0	0	3	3	0	3	3	3	3	3	3	3
5	Airlift Obj Score	3	3	3	2	3	3	3	1	3	3	3	2	3	3	3	3	3	3	3
6																				
7	Create constraint that Hub Airlift Totals >= Hubs																			
8																				
9	Null Factor	-3																		

	A	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN
2		Luke	Malmstrom	McChord	McConnell	McGuire	Minot	Moody	Mt Home	Nellis	Patrick	Peterson (SchrieverBuckley)	Robins	Scott	Seymour Johnson	Shaw	Sheppard	Tinker	Travis	Vandenberg	Whiteman
3	Hub Airlift Totals	0	0	0	0	0	1	2	0	0	0	0	0	0	0	2	3	0	0	0	3
4	Hubs?	3	3	3	3	3	0	0	3	3	3	3	3	3	3	0	0	3	3	3	0
5	Airlift Obj Score	3	3	3	3	3	1	2	3	3	3	3	3	3	3	2	3	3	3	3	3

Figure D.9 – Screenshot of Airlift Calc Tab

Appendix D

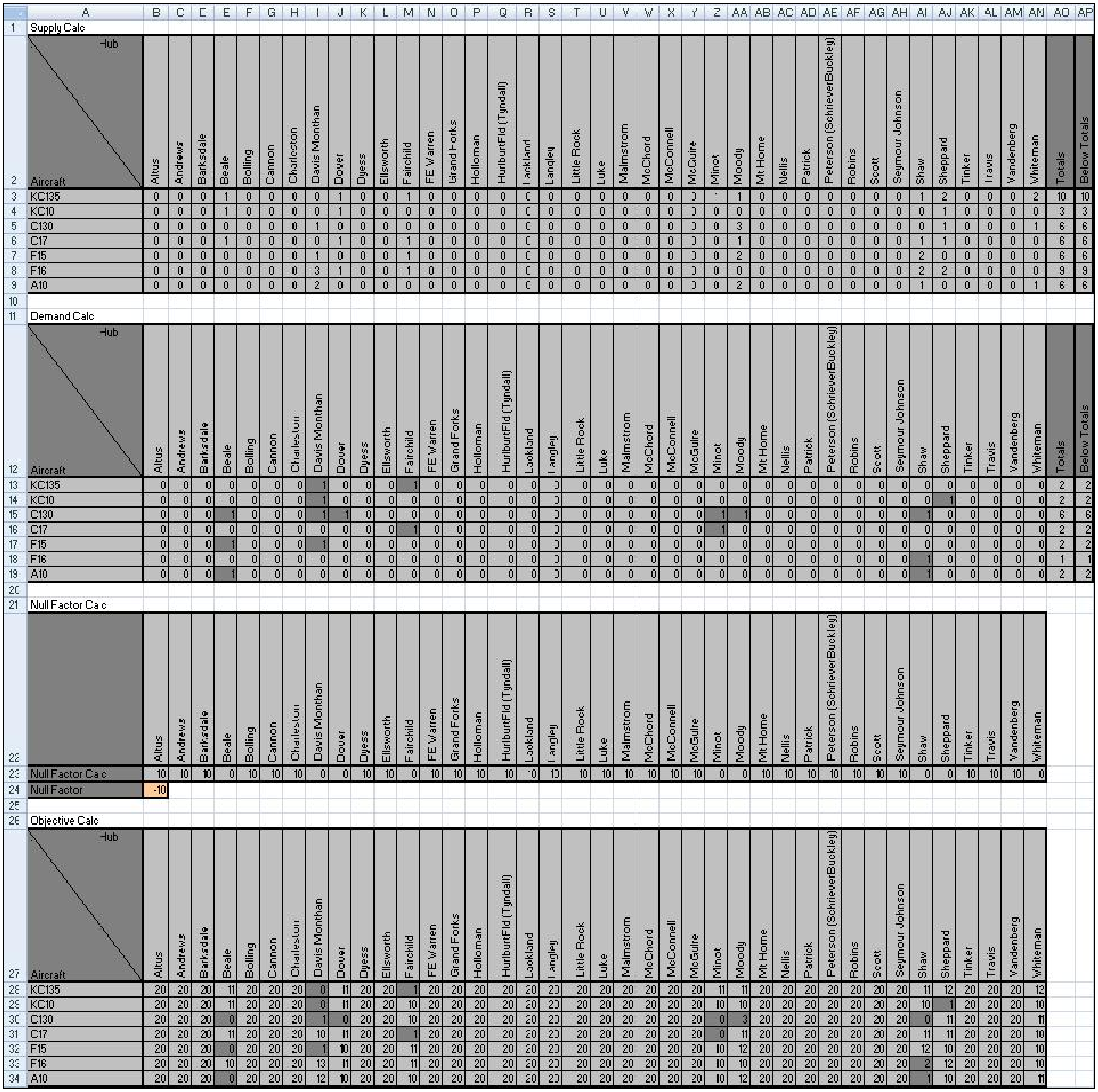
Cold Wx Calc Tab

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	Calculation																				
2		Altus	Andrews	Barksdale	Beale	Bolling	Cannon	Charleston	Davis Monthan	Dover	Dyess	Ellsworth	Fairchild	FE Warren	Grand Forks	Holloman	HurlburtFld (Tyndall)	Lackland	Langley	Little Rock	Luke
3	# CW Bases	0	0	0	0	0	0	0	1	0	0	0	4	0	0	0	0	0	0	0	0
4	CW FOBs:																				
5	Manas	4	4	4	4	4	4	4	4	4	4	4	0	4	4	4	4	4	4	4	4
6	CW Obj Score	4	4	4	4	4	4	4	5	4	4	4	4	4	4	4	4	4	4	4	4
7																					
11	Null Factor	-4																			

	A	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO
1	Calculation																				
2		Malmstrom	McChord	McConnell	McGuire	Minot	Moody	Mt Home	Nellis	Patrick	Peterson (SchneverBuckley)	Robins	Scott	Seymour Johnson	Shaw	Sheppard	Tinker	Travis	Vandenberg	Whiteman	Total
3	# CW Bases	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
4	CW FOBs:																				
5	Manas	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
6	CW Obj Score	4	4	4	4	6	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
7																					
11	Null Factor																				

Figure D.10 – Screenshot of Cold Wx Calc Tab

Mission Calc Tab



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP
1	Supply Calc																																									
2	Hub / Aircraft	Altus	Andrews	Barksdale	Beale	Bolling	Cannon	Charleston	Davis Monthan	Dover	Dyess	Ellsworth	Fairchild	FE Warren	Grand Forks	Holloman	HurlburtFld (Tyndall)	Lackland	Langley	Little Rock	Luke	Malmstrom	McChord	McConnell	McGuire	Minot	Moody	Mt Home	Nellis	Patrick	Peterson (SchrieverBuckley)	Robins	Scott	Seymour Johnson	Shaw	Sheppard	Tinker	Travis	Vandenberg	Whiteman	Totals	Below Totals
3	KC135	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	2	0	0	0	2	10	10
4	KC10	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3	3
5	C130	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	1	0	0	0	1	6	6
6	C17	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	6	6
7	F15	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	6	6
8	F16	0	0	0	0	0	0	0	3	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	9	9
9	A10	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	1	6	6
10																																										
11	Demand Calc																																									
12	Hub / Aircraft	Altus	Andrews	Barksdale	Beale	Bolling	Cannon	Charleston	Davis Monthan	Dover	Dyess	Ellsworth	Fairchild	FE Warren	Grand Forks	Holloman	HurlburtFld (Tyndall)	Lackland	Langley	Little Rock	Luke	Malmstrom	McChord	McConnell	McGuire	Minot	Moody	Mt Home	Nellis	Patrick	Peterson (SchrieverBuckley)	Robins	Scott	Seymour Johnson	Shaw	Sheppard	Tinker	Travis	Vandenberg	Whiteman	Totals	Below Totals
13	KC135	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
14	KC10	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	2
15	C130	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	6	6
16	C17	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
17	F15	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
18	F16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1
19	A10	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	2
20																																										
21	Null Factor Calc																																									
22		Altus	Andrews	Barksdale	Beale	Bolling	Cannon	Charleston	Davis Monthan	Dover	Dyess	Ellsworth	Fairchild	FE Warren	Grand Forks	Holloman	HurlburtFld (Tyndall)	Lackland	Langley	Little Rock	Luke	Malmstrom	McChord	McConnell	McGuire	Minot	Moody	Mt Home	Nellis	Patrick	Peterson (SchrieverBuckley)	Robins	Scott	Seymour Johnson	Shaw	Sheppard	Tinker	Travis	Vandenberg	Whiteman		
23	Null Factor Calc	10	10	10	0	10	10	10	0	0	10	10	0	10	10	10	10	10	10	10	10	10	10	10	10	0	0	10	10	10	10	10	10	10	0	0	10	10	10	0		
24	Null Factor	-10																																								
25																																										
26	Objective Calc																																									
27	Hub / Aircraft	Altus	Andrews	Barksdale	Beale	Bolling	Cannon	Charleston	Davis Monthan	Dover	Dyess	Ellsworth	Fairchild	FE Warren	Grand Forks	Holloman	HurlburtFld (Tyndall)	Lackland	Langley	Little Rock	Luke	Malmstrom	McChord	McConnell	McGuire	Minot	Moody	Mt Home	Nellis	Patrick	Peterson (SchrieverBuckley)	Robins	Scott	Seymour Johnson	Shaw	Sheppard	Tinker	Travis	Vandenberg	Whiteman		
28	KC135	20	20	20	11	20	20	20	0	11	20	20	1	20	20	20	20	20	20	20	20	20	20	20	20	11	11	20	20	20	20	20	20	20	11	12	20	20	20	12		
29	KC10	20	20	20	11	20	20	20	0	11	20	20	10	20	20	20	20	20	20	20	20	20	20	20	20	10	10	20	20	20	20	20	20	20	10	1	20	20	20	10		
30	C130	20	20	20	0	20	20	20	1	0	20	20	10	20	20	20	20	20	20	20	20	20	20	20	20	0	3	20	20	20	20	20	20	20	0	11	20	20	20	11		
31	C17	20	20	20	11	20	20	20	10	11	20	20	1	20	20	20	20	20	20	20	20	20	20	20	20	0	11	20	20	20	20	20	20	20	11	11	20	20	20	10		
32	F15	20	20	20	0	20	20	20	1	10	20	20	11	20	20	20	20	20	20	20	20	20	20	20	20	10	12	20	20	20	20	20	20	20	12	10	20	20	20	10		
33	F16	20	20	20	10	20	20	20	13	11	20	20	11	20	20	20	20	20	20	20	20	20	20	20	20	10	10	20	20	20	20	20	20	20	2	12	20	20	20	10		
34	A10	20	20	20	0	20	20	20	12	10	20	20	10	20	20	20	20	20	20	20	20	20	20	20	20	10	12	20	20	20	20	20	20	20	1	10	20	20	20	11		

Figure D.11 – Mission Calc Tab

Optimization Summary Tab

Appendix C provides a snapshot of this tab for each of the tested Scenarios as Table C.1 through Table C.8. The Optimization Summary Tab summarizes the values obtained in the current solution. The summary data is self-explanatory.

Base Info Tab

Chapter 3 provides a snapshot of this tab in Table 3.3. The Base Info Tab is a summary of all the defined data for all home station bases that the model includes. This data consists of CE career field manpower levels and binary indicators for base missions, airlift availability, and cold weather status.

FOB Rqmts Tab

Chapter 3 provides a snapshot of this tab in Table 3.2. The FOB Rqmts Tab is a summary of all the defined data for all FOBs that the model includes. The data consist of CE career field manpower requirements and binary indicators for base missions.

Distance Table Tab

Chapter 3 provides a snapshot of this tab in Table 3.1. The Distance Table Tab contains a mileage matrix for all possible Hub-Spoke combinations. These distance values come from the Department of Defense table of Official Distances, at dtod.sddc.army.mil.

Map Tab

Chapter 2 provides a snapshot of this tab in Figure 2.2. The Map Tab provides a graphical representation of all Air Force bases that the model includes for consideration as a Hub or Spoke.

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14. ABSTRACT The purpose of this research is to develop a multiple-objective mixed-integer linear programming model that determines the feasibility of a new deployment paradigm, which offers greater flexibility to home station and deployed location civil engineers (CE) by applying hub-and-spoke networking. The research covers the histories of CE and Air and Space Expeditionary Force (AEF), current CE deployment needs, multiple-objective decision analysis, hub-and-spoke networking, and organizational behavior benefits of the new paradigm. The methodology section provides details on each objective, explains the model, defines weights, and explains the objective function's calculation. Next, an analysis of the model's resulting scenarios helps determine the appropriate parameters. Research conclusions and recommendations for potential future study are provided. Some of the new paradigm's benefits include the consolidation of coordination, training, equipment, travel, and other mobility related activities. The paradigm provides home station and deployed CE leaders with greater control over the mobilization of their resources. This control should help to reduce fluctuations in home station manpower levels, and deployment to the same location should make the process easier for everyone involved. A final added benefit to regional clustering is that it opens the door to improved networking between active duty and guard/reserve components.

15. SUBJECT TERMS Linear Programming, Mixed-Integer, Multiple-Objective, Hub-and-Spoke Networks, Manpower, Mobilization, Deployments, and Civil Engineering

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